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Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus Total Maximum Daily Load Study

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Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus Total Maximum Daily Load Study

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Abstract

As part of the Wenatchee River Total Maximum Daily Load (TMDL) study, the Washington State Department of Ecology conducted a water quality monitoring and modeling study during 2002-2004. This document summarizes the quality assurance of the data, and reports findings of the monitoring and modeling.

Dissolved oxygen concentrations in the upper Wenatchee River and Icicle Creek (Class AA reaches) are likely to be lower than the 9.5 mg/L criterion during the summer due to the high land elevations and high water temperature. Implementation of the Wenatchee River temperature TMDL will improve dissolved oxygen in the tributaries. Reserve load capacities for biochemical oxygen demand (BOD) and nutrients to maintain water quality standards are recommended for the Class AA reaches of the Wenatchee River and Icicle Creek.

Observed data and model simulations showed that dissolved oxygen and pH exceedances in the lower Wenatchee River and Icicle Creek (Class A reaches) were caused by periphyton (attached algae) growth. Phosphorus is the most limiting nutrient that controls periphyton growth and biomass. Loading sources and assimilative capacities for inorganic phosphorus were determined for the Wenatchee River and Icicle Creek by using the QUAL2K water quality model.

Modeling of critical conditions in the lower Wenatchee River and Icicle Creek showed assimilative capacities of 7.7 kg/day and 0.65 kg/day of inorganic phosphorus, respectively, representing 80% and 55% reductions from current loading conditions, respectively. The model also showed that assimilative capacities for the lower Wenatchee River and Icicle Creek can be represented by instream maximum inorganic phosphorus concentrations of 3.1 ug/L and 4.4 ug/L, respectively.

Acknowledgements

The Wenatchee River basin TMDL study included a partnership between the Department of Ecology and the Water Resource Inventory Area (WRIA) 45 Water Quality Technical Subcommittee (consisting of Ecology TMDL staff and the WRIA 45 Watershed Planning Unit's Water Quality Subcommittee). Ecology authored this TMDL technical report for dissolved oxygen, pH, and phosphorus, and the Water Quality Technical Subcommittee reviewed, discussed, and commented on the report.

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Executive Summary

Introduction

The Wenatchee River and Icicle Creek are included on Washington State's list of water-quality-impaired waters because of low dissolved oxygen (DO) and high pH.

As part of the Wenatchee River basin Total Maximum Daily Load (TMDL) study for DO and pH, the Washington State Department of Ecology (Ecology) collected stream water quality data during 2002-2003 for the Wenatchee River and Icicle Creek.

Wenatchee River Basin

The Wenatchee River Basin is located in the central part of Washington State (Figure ES-1). The Wenatchee River originates at the outflow from Lake Wenatchee, drains an area of about 1371 square miles, and flows southeast until it meets the Columbia River at the city of Wenatchee.

Annual average precipitation throughout the subbasin ranges from 150 inches at the crest of the Cascade Mountains to 8.5 inches in the city of Wenatchee.

The Wenatchee River and Icicle Creek are Class AA waters just above the city of Leavenworth, and Class A below (for water quality standards classifications). The cities of Leavenworth, Peshastin, and Cashmere have public-owned treatment works that discharge treated wastewater to the lower Wenatchee River year-round.

Stream water quality assessment

- Three synoptic surveys were conducted on the Wenatchee River and Icicle Creek during the dry months of 2002 (July, August, and September), and one synoptic survey was conducted in April 2003. During each synoptic survey, data were collected from numerous sites within a short time period (1-2 days).
- In general, DO levels below (not in compliance with) the Class AA 9.5 mg/L criterion were observed throughout the Class AA (upper) reaches of the Wenatchee River and Icicle Creek. Also, pH levels above the Class A 8.5 criterion were observed throughout the Class A (lower) reaches of the Wenatchee River and Icicle Creek during the dry low-flow season of 2002 and near the mouth of the Wenatchee River in April 2003.

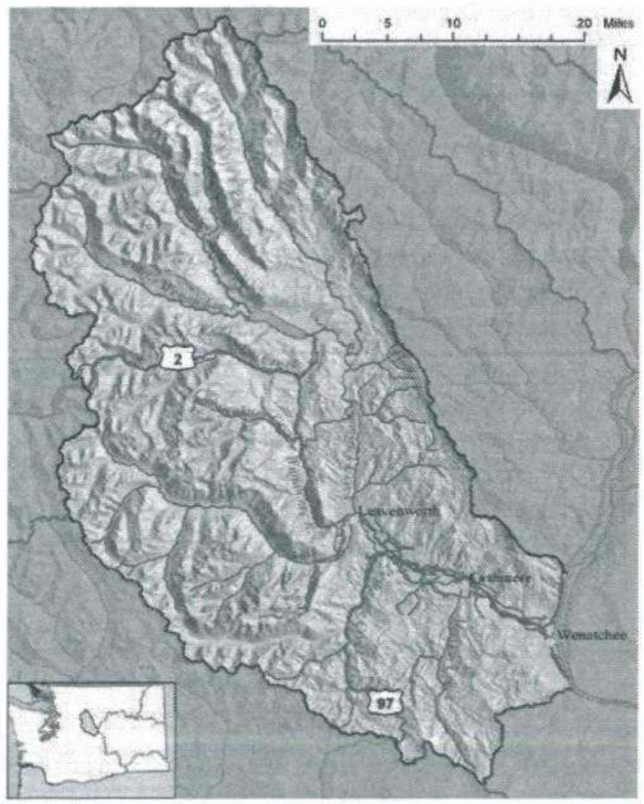


Figure ES-1. Study area map for the Wenatchee River basin DO, pH, and phosphorus TMDL

- Data collected in the upper reaches of the Wenatchee River and Icicle Creek showed that DO levels were not in compliance with the water quality criterion because high land elevations and high water temperatures cause DO saturation to be less than the 9.5 mg/L DO criterion (Figure ES-2).

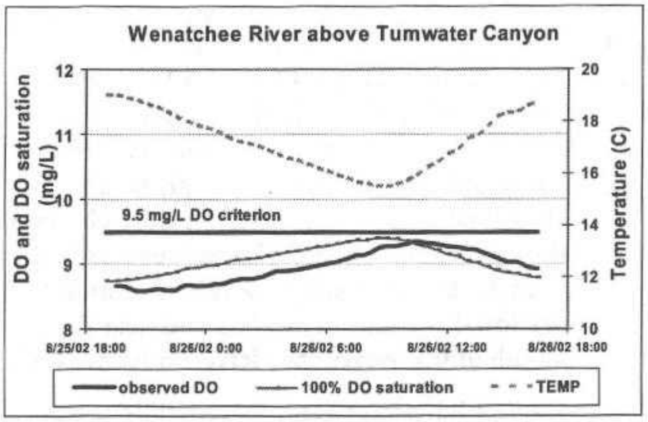


Figure ES-2. DO levels in Class AA water on August 26, 2002 were below the 9.5 mg/L criterion due to low DO saturation resulting from high land elevation and water temperature.

- Data collected in the lower reaches of the Wenatchee River and Icicle Creek showed the pH levels were high (above the 8.5 pH criterion) during the afternoon because of algal photosynthesis (Figure ES-3).

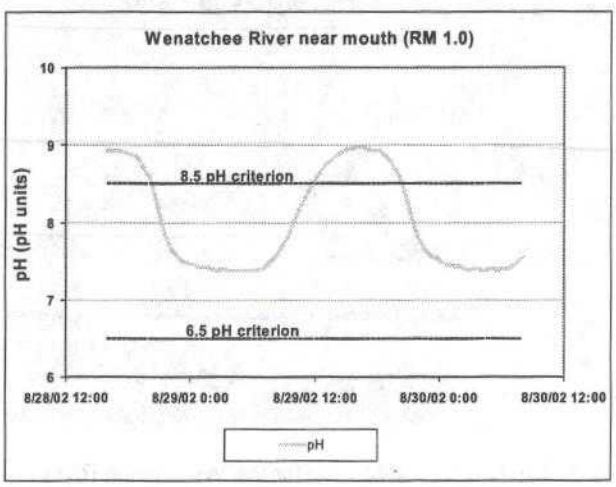


Figure ES-3. pH levels in Class A water on August 28-29, 2002 were above the 8.5 pH criterion in the afternoon due to algal photosynthesis.

- Phosphorus sampling was conducted to investigate its connection with algal photosynthesis and pH. High pH results from algal photosynthesis when excessive nutrients (phosphorus) are introduced to a stream. Acting as a fertilizer, phosphorus "feeds" algae attached to rocks in the streambed.

- Phosphorus loading in the lower Wenatchee River (Figure ES-4) and Icicle Creek is fueling excessive algal photosynthesis.

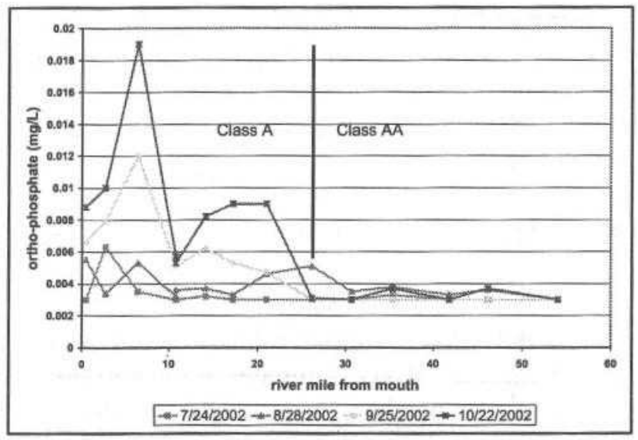


Figure ES-4. Ortho-phosphate (dissolved phosphorus) concentrations increased in a downstream direction in the lower Wenatchee River, particularly during low-flow months.

Water quality modeling

Steady-flow models of pH and attached algae, based on EPA's QUAL2K water-quality model, were developed for the Wenatchee River and Icicle Creek to evaluate the capacity of each waterbody to assimilate phosphorus loads and still meet water quality standards.

The Wenatchee River and Icicle Creek models were calibrated to data collected during synoptic surveys in August and September 2002. The model-predicted pH had an overall error of approximately 0.2 pH units when comparing simulated and observed pH values (an excellent fit for pH modeling).

At current critical-condition wastewater flows and treatment levels, 43% of the dissolved phosphorus load to the lower Wenatchee River is from wastewater, 47% is from diffuse sources, and nearly 5% is from tributaries (Table ES-1). Two diffuse-source reaches of the lower Wenatchee River exhibit higher diffuse phosphorus loading than other reaches. Of these reaches, one brackets the city of Dryden and the other brackets the city of Cashmere.

Table ES-1. Critical-condition dissolved phosphorus loads and assimilative capacity in the lower Wenatchee River.

Wenatchee River Critical-Condition Dissolved Phosphorus Loads	kg/day	kg/day	% of total load
Upstream Load		1.24	3.2%
NPDES Point Source Loads (90th percentile loads)		16.78	42.7%
Leavenworth POTW	7.557		
Peshastin POTW	1.609		
Cashmere POTW	6.780		
Cashmere POTW lagoon leak (estimated)	0.837		
General Permit Loads (non-contact cooling water)		0.02	0.1%
Blue Bird	0.016		
Blue Star	0.001		
Bardin Growers	0.004		
Tributary Loads		1.75	4.4%
Icicle Creek	0.802		
Chumstick Creek	0.097		
Peshastin Creek	0.153		
Brender Creek	0.339		
Mission Creek	0.354		
Irrigation Spill Returns		0.29	0.7%
Cascade Orchard	0.059		
Icicle Irrigation spill near Leavenworth	0.000		
Icicle Irrigation spill at Stines Hill	0.031		
Icicle Irrigation spill at Fairview Canyon	0.047		
Jones Shotwell spill return	0.044		
Wenatchee Reclamation District spill	0.107		
Diffuse Loads (groundwater)		19.23	48.9%
Diffuse load between RM 26.2 and RM 21.0 (Leavenworth)	1.944		
Diffuse load between RM 21.0 and RM 17.2 (Peshastin)	2.583		
Diffuse load between RM 17.2 and RM 14.1 (Dryden)	4.478		
Diffuse load between RM 14.1 and RM 10.8	2.856		
Diffuse load between RM 10.8 and RM 6.5 (Cashmere)	7.036		
Diffuse load between RM 6.5 and RM 2.8 (Monitor)	0.335		
Load Abstractions		-2.39	
Wenatchee Reclamation District diversion	-1.869		
Jones Shotwell diversion	-0.439		
Gunn Ditch diversion	-0.083		
Total Loading		39.31	
Total Loading (minus abstractions)		36.92	
Dissolved Phosphorus Assimilative Capacity		7.76 kg/day	
Excess Dissolved Phosphorus Loading		29.16 kg/day	

At current critical-condition loads, most of the dissolved phosphorus loading to lower Icicle Creek is from the Leavenworth National Fish Hatchery main outfall (e.g., over 85%) (Table ES-2).

Table ES-2. Critical-condition dissolved phosphorus loads and assimilative capacity load in lower Icicle Creek.

Lower Icicle Creek Critical-Condition Dissolved Phosphorus Loads	kg/day	kg/day	% of total load
Upstream Load		0.01	0.8%
Point Source Loads		1.25	86.3%
Leavenworth National Fish Hatchery (main outfall)	1.191		
Leavenworth National Fish Hatchery (abatement pond discharge)	0.062		
Diffuse Loads (groundwater)		0.19	12.9%
Diffuse load between RM 2.9 (hatchery) and RM 2.3 (E. Leavenworth Rd.)	0.061		
Diffuse load between RM 2.3 and mouth	0.126		
Total Loading		1.45	
Dissolved Phosphorus Assimilative Capacity		0.65 kg/day	
Excess Dissolved Phosphorus Loading		0.80 kg/day	

Critical-load model simulations performed at 7-day average, 10-year return period (7Q10) flow conditions showed that the lower Wenatchee River (from Leavenworth to the mouth) can assimilate about 7.7 kg/day of dissolved phosphorus and still meet pH water quality standards. The lower Icicle Creek (from the Leavenworth National Fish Hatchery to the mouth) can assimilate about 0.65 kg/day.

Mass-balance modeling shows that the current dissolved phosphorus loadings to the lower Wenatchee River (Table ES-1) and lower Icicle Creek (Table ES-2) exceed (fail to meet) their respective assimilative capacities.

Conclusions

- The Wenatchee River and Icicle Creek are very sensitive to the addition of nutrients. Although inorganic phosphorus levels are relatively low (less than 20 ug/L) compared to other Washington State streams, they are currently too high in the lower reaches to comply with the pH water quality standards.

- Large reductions of phosphorus are needed from both point and nonpoint sources in the lower Wenatchee River and Icicle Creek.

- The Wenatchee River Basin Temperature TMDL recommendations to improve water temperatures will improve minimum DO in the Class AA tributaries and reaches of the Wenatchee River and Icicle Creek.

- To maintain water quality standards in the upper Wenatchee River and Icicle Creek, reserve load capacities for biological oxygen demand (BOD) and nutrients are recommended.

Introduction

The Wenatchee River and Icicle Creek were included on Washington State's 1998 list of impaired waters because of dissolved oxygen (DO) and pH water quality standard violations (Table 1). This list, called the 303(d) list because it is required by section 303(d) of the federal Clean Water Act, contains waterbodies that are not meeting water quality standards.

The Clean Water Act mandates that Washington State establish Total Maximum Daily Loads (TMDLs) for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) have promulgated regulations (40 CFR 130) and developed guidance (EPA, 1991, 1997, 1999; Ecology, 1991, 1996, 1999) for establishing TMDLs.

Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses, such as fish spawning and drinking water supply, and criteria, usually numeric criteria, to achieve those uses. When a lake, river, or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the waterbody on a list of "impaired" waterbodies and to prepare an analysis called a TMDL.

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources. If the pollutant comes from a discrete (point) source such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse (nonpoint) sources such as general urban, residential, or farm runoff, the cumulative share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

Consequently, in June 2002, Ecology began water quality monitoring as part of a TMDL technical study of DO and pH in the Wenatchee River watershed. The monitoring focused on the mainstem Wenatchee River and Icicle Creek. The study area is in the Wenatchee River watershed (Figure 1).

Table 1. Stream reaches on the 1998 303(d) *** list for impaired waterbodies.

Stream	WBID (segment)	Parameter	Section
Brender Creek	WA-45-1100*	Fecal Coliform Dissolved Oxygen	T23N, R19E, Section 5
Chiwaukum Creek	WA-45-1900*	Temperature	T25N, R17E, Section 9
Chumstick Creek	WA-45-1200*	Dissolved Oxygen, pH Fecal Coliform	T24N, R17E, Section 1
	WA-45-1200*	Instream Flow	T26N, R18E, Section 30
Icicle Creek	WA-45-1017*	Dissolved Oxygen**	T24N, R17E, Section 24
	WA-45-1015*	Instream Flow	T24N, R17E, Section 13
	WA-45-1017*	Temperature	T24N, R17E, Section 30
Icicle Creek	WA-45-1017*	Dissolved Oxygen**	T24N, R16E, Section 24
Little Wenatchee River	WA-45-4000*	Temperature	T27N, R16E, Section 15
Mission Creek	WA-45-1011*	Instream Flow	T23N, R19E, Section 8
	WA-45-1011*	Fecal Coliform	T23N, R19E, Section 5
	WA-45-1011	4,4' –DDT, 4,4' -DDE Guthion	T23N, R19E, Section 4
	WA-45-1011*	DDT	T23N, R19E, Section 9
Nason Creek	WA-45-3000*	Temperature	T26N, R17E, Section 9
	WA-45-3000*	Temperature	T27N, R17E, Section 27
Peshastin Creek	WA-45-1013*	Temperature Instream Flow	T24N, R18E, Section 21
	WA-45-1014*	Temperature	T24N, R18E, Section 32
Wenatchee River	WA-45-1010*	Instream Flow	T24N, R18E, Section 17
	WA-45-1010*	pH** Temperature	T23N, R20E, Section 28
	WA-45-1020*	Dissolved Oxygen**	T25N, R17E, Section 9
	WA-45-1020*	Instream Flow	T26N, R17E, Section 12

* Also listed on the 1996 303(d) List.
** Listings addressed in this technical study.
*** Table 15 contains the latest 2004 DO and pH listings for WRIA 45

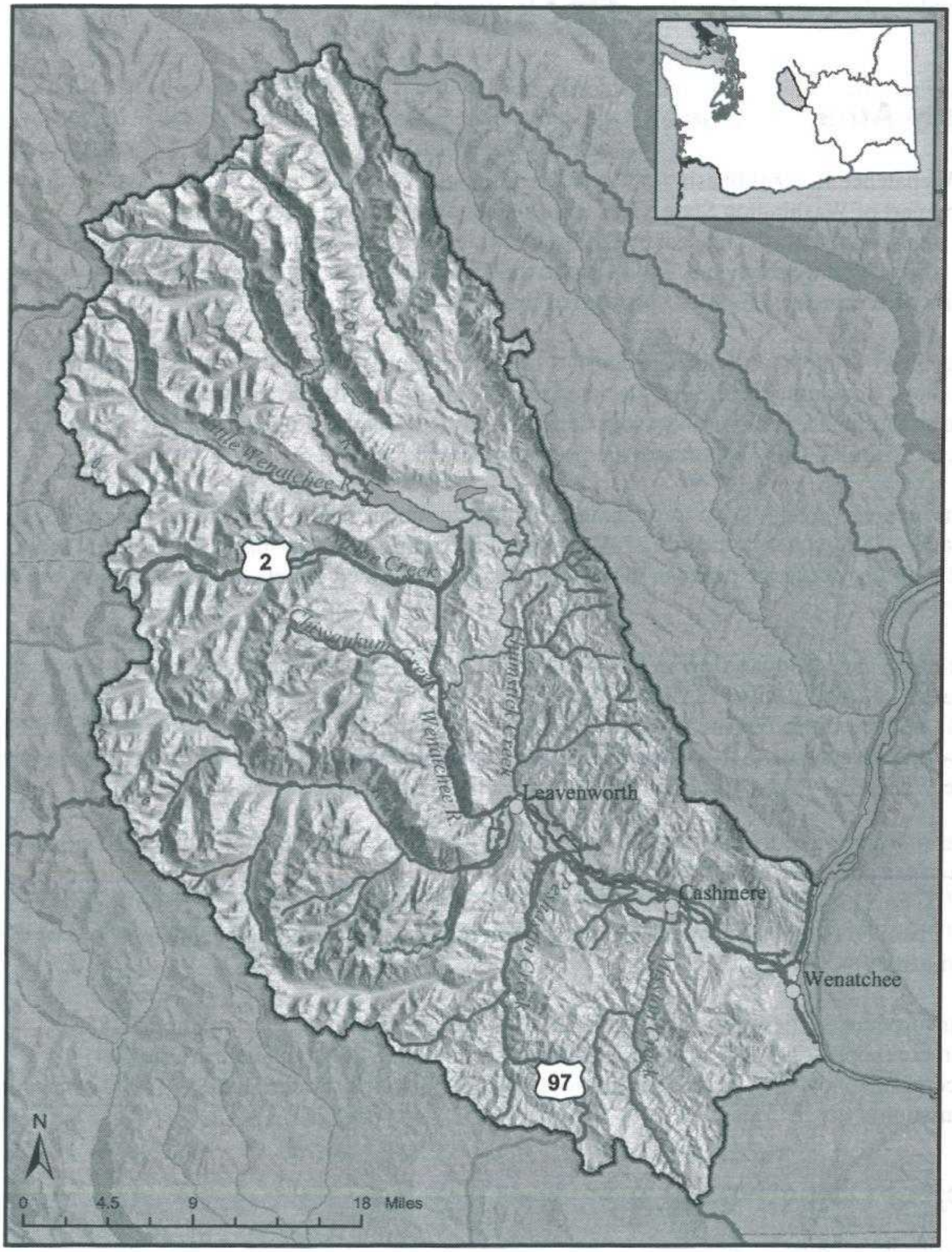


Figure 1. Study area for the Wenatchee River TMDL study.

Background

Study Area

The Wenatchee River subbasin (WRIA 45) encompasses 878,423 acres and is located in the central part of Washington State. The subbasin is bounded on the west by the Cascade Mountians, on the north and east by the Entiat Mountains, and on the south by the Wenatchee Mountains. The Wenatchee is a subbasin to the Columbia River basin and enters that system at the city of Wenatchee 15 miles upstream of the Rock Island Dam.

The geology of the upper subbasin consists of high and low relief landtypes associated with glaciation (e.g. cirque headwalls, glaciated ridges, and glacial/fluvial outwash). The middle part of the subbasin is a mixture of igneous and basalt rock formations and glacial/fluvial outwash terraces. Alluvial fans and terraces are predominant landtypes in the lower Wenatchee.

Annual average precipitation throughout the subbasin ranges from 150 inches at the crest of the Cascades to 8.5 inches in the city of Wenatchee. Streamflow varies during the year, but the mean monthly discharge peaks in the spring from the combined effects of snowmelt and rain-on-snow events.

Most of the annual streamflow in the Wenatchee River originates from tributaries in the upper subbasin: the White River (25%), Icicle Creek (20%), Nason Creek (18%), Chiwawa River (15%), and the Little Wenatchee River (15%) (Andonaegui, 2001). Both the White and Little Wenatchee rivers enter Lake Wenatchee in the upper subbasin; the mouth of the lake is the head of the Wenatchee River, and Nason Creek enters the river just below the lake outlet.

There is a mixture of federal, state, county, and private land ownership throughout the subbasin. Most of the upper subbasin is designated federal wilderness area and is under the jurisdiction of the U.S. Forest Service Lake Wenatchee and Leavenworth Ranger Districts. State Highways 2 and 97 parallel much of the Wenatchee mainstem and Nason Creek, and contain portions of their streambanks.

The incorporated cities designated in the 2000 census are Wenatchee (population 27,856), Cashmere (population 2,965), and Leavenworth (population 2,074). There are smaller unincorporated towns and communities located along State Highways 2 and 97 (2000 census information).

Project Objectives

The objectives of the study were to:

1. Conduct water quality monitoring surveys for physical, chemical, and biological parameters to determine sources affecting dissolved oxygen and pH levels in the Wenatchee River, Icicle Creek, and their tributaries.

2. Assess or model productivity in streams using data from all parameters collected during the surveys.

3. Set dissolved oxygen and pH TMDL targets, nonpoint load allocations, and point source wasteload allocations for parameters responsible for causing dissolved oxygen and pH exceedances[1] in the Wenatchee River and Icicle Creek.

[1] Levels not meeting Washington State standards

Methods

Study Design

Field personnel from Ecology and the Chelan County Conservation District collected water quality data during a series of surveys. Surveys were conducted on the 14 dates shown in Table 2.

Table 2. Sampling dates for years 1 and 2.

2002	2003
June 4 – 6	January 6 – 7
June 25 – 26	April 7 – 9
July 8 – 9	
July 22 – 24	
August 5 – 6	
August 26 – 28	
September 9 – 10	
September 23 – 25	
October 9	
October 21 – 22	
November 12 – 13	
December 2 – 3	

Sampling events (June 2002 through April 2003) covered 42 stations in the mainstem Wenatchee River drainage and 18 stations in the Icicle Creek drainage. The sampling stations were divided, and two teams of two samplers each sampled all 60 sites over the course of three days. Hydrolab® meters were used by each team to collect pH, conductivity, dissolved oxygen, and temperature measurements. Laboratory parameters for each site are described in the Quality Assurance Project Plan (Bilhimer et al., 2002), and methods are shown in Tables 3 and 4.

Table 3. Summary of field measurements and methods.

Parameter	Method
Velocity	Marsh-McBirney current meter
Specific Conductivity	Hydrolab meter
pH	Hydrolab meter
Temperature	Hydrolab meter
Dissolved Oxygen	Hydrolab meter Winkler modified azide (EPA 360.20)

Table 4. Summary of laboratory measurements and methods.

Parameter	EPA Method
Alkalinity	SM2320
Biochemical Oxygen Demand	405.1
Chloride	300.0
Chlorophyll a	SM 10200H(3)[1]
Dissolved Organic Carbon	415.1
Ammonia	SM4500NH3H
Nitrate/Nitrite	SM4500NO3I
Nitrogen – Total Persulfate	SM4500NB
Orthophosphate	SM4500PG
Phosphorus, total	365.3
Phosphorus, total low-level	200.8M
Total Suspended Solids	SM2540D
Total Nonvolatile Suspended Solids	160.4
Total Dissolved Solids	160.1
Total Organic Carbon	415.1
Turbidity	SM2130
Fecal Coliform	SM MF 9222D[1]

[1] SM indicates Standard Methods rather than EPA method.

In addition to the sampling events listed above, the following data-collection approaches were used to gather data to meet the objectives of this study:

1. Field measurement surveys to collect continuous data from selected mainstem Wenatchee River and Icicle Creek sites.
2. Point source discharge water quality surveys conducted concurrently with intensive sampling events.
3. Groundwater surveys assessing relative surface water and groundwater head relationships, groundwater temperature, and water quality.
4. Travel time estimates in the mainstem Wenatchee River.

Data Quality Objectives and Analytical Procedures

Target accuracy, precision, and bias, as well as required reporting limits, are listed in Table 5.

Table 5. Targets for accuracy, precision, and bias, and reporting limits for the sample measurement.

Analysis	*Accuracy* % deviation from true value	*Precision* Relative Standard Deviation (%)	*Bias* % deviation from true value	*Required Reporting Limits* Concentration units
Field				
Velocity*	± 2% of reading; 0.1 f/s	N/A	N/A	0.05 f/s
pH*	0.20 s.u.	N/A	0.10 s.u.	N/A
Water Temperature*	± 0.2°C			N/A
Dissolved Oxygen	N/A	N/A	5	1 mg/L
Specific Conductivity	N/A	N/A	5	1 umhos/cm
Laboratory				
Alkalinity	25	<10	5	10 mg/L
Ammonia Nitrogen	25	<10	5	10 ug/L
Biochemical Oxygen Demand	N/A	<25	N/A	2 mg/L
Chloride	15	< 5	5	0.1 mg/L
Chlorophyll a	50	<20	10	0.05 ug/L
Dissolved Organic Carbon	30	<10	10	1 mg/L
Fecal Coliform (MF)	N/A	<25	N/A	1 cfu/100 mL
Nitrate-Nitrite Nitrogen	25	<10	5	10 ug/L
Orthophosphate	25	<10	5	3 ug/L
Total Dissolved Solids	30	<10	10	1 mg/L
Total Nonvolatile Suspended Solids	N/A	<10	N/A	1 mg/L
Total Organic Carbon	30	<10	10	1 mg/L
Total Persulfate Nitrogen	30	<10	10	25 ug/L
Total Phosphorus	25	<10	5	3 ug/L
Total Suspended Solids	30	<10	10	1 mg/L
Turbidity	30	<10	10	1 NTU

* As units of measurement, not percentages

Sample Collection and Field Measurements

Ecology field personnel collected water quality data during surveys conducted in 2002 and 2003. The methods used in these surveys were initially described in the Quality Assurance (QA) Project Plan (Bilhimer et al., 2002). However, several stations changed according to logistical needs and information acquired from sampling. Figures 2 through 4 show all of the sampling site locations divided by sub-watershed. Tables 6 through 8 list the sampling station identification (which includes the river mile), description, and latitude and longitude of the sampling sites, as well as the general type of data collected at each site.

All river water quality samples collected for laboratory analysis were grab samples taken just below the water surface from the main body of flow (unless there was not enough depth to submerse the sample container). Samples were collected either by using an extension rod extended from the streambank or by wading into the river. Generally, grab samples were collected once per day.

Instantaneous river temperature, DO, pH and conductivity were measured using Hydrolab® Datasonde 3s and 4s. Hydrolab® DO measurements were compared to DO measurements using the azide modified Winkler method.

In situ multi-parameter data loggers (Hydrolab® Datasonde 3s and 4s) were deployed at different locations in the mainstem Wenatchee River and Icicle Creek to collect continuous diel data for DO, temperature, pH, and conductivity. The locations where diel data was collected are listed in Tables 6 through 8. These data were used to assess diel changes in the parameters measured.

Point sources listed in the QA Project Plans were sampled during the intensive synoptic surveys by Ecology's Toxics Studies Unit. Appendix A lists the permit limits and background information of the Wenatchee TMDL point sources. Final effluents were sampled during periods when they discharge to receiving waters. Generally, two grab samples per day and 24-hour composite samples were collected. Appendix B contains a summary of the field notes from the point source sampling, describing the sample collection and field measurements.

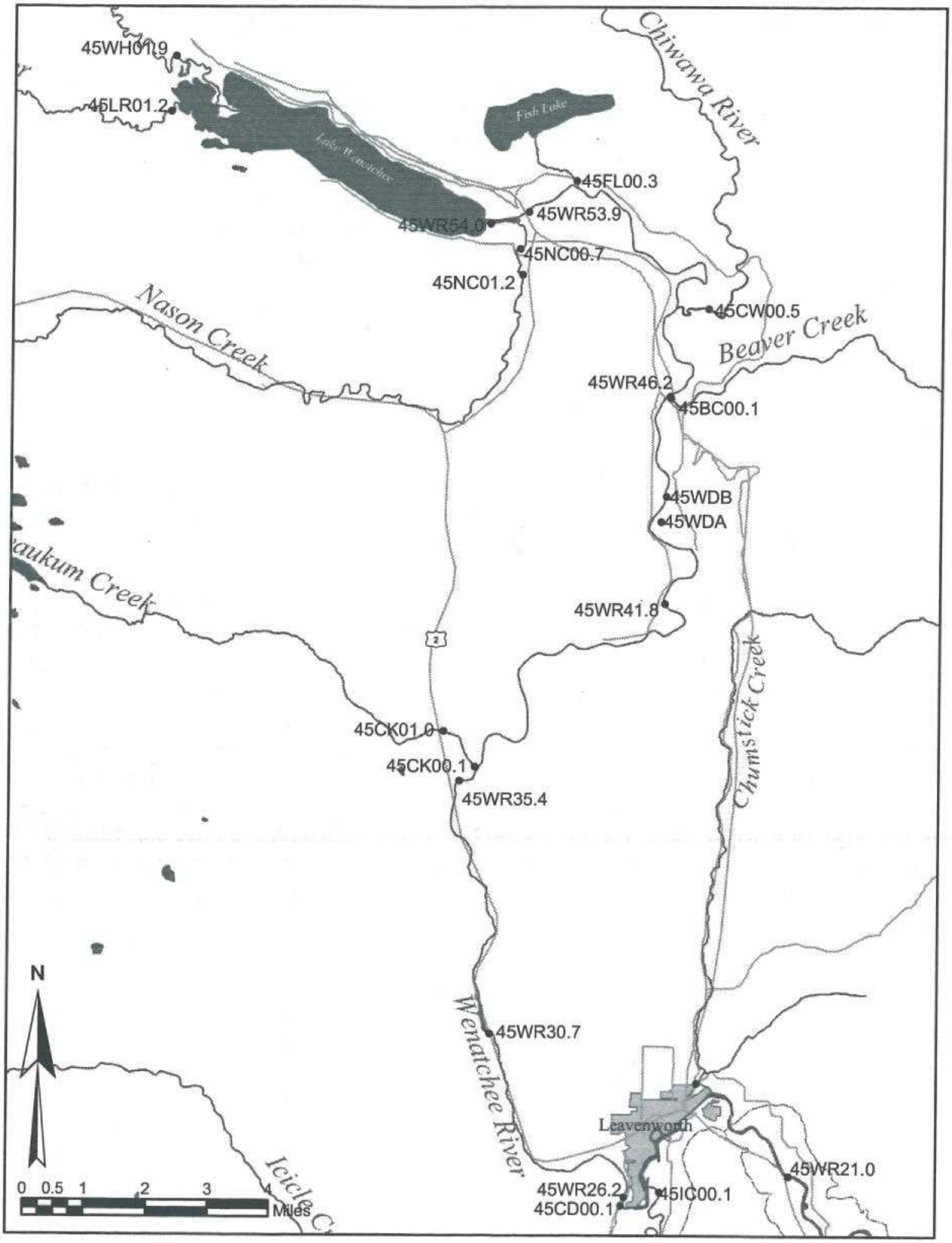


Figure 2. Upper mainstem Wenatchee River sampling stations for the 2002-03 TMDL study.

Table 6. Upper mainstem Wenatchee River sample site identification, description, and location.

Station ID (includes RM)	Station Name	Type of Field Measurement	Longitude	Latitude
45BC00.1	Beaver Cr nr mouth	Grab samples, instantaneous flow	-120.6603	47.7669
45CD00.1	Cascade Orchards irrigation return	Grab samples, continuous flow station	-120.6749	47.5756
45CK00.1	Chiwaukum Cr nr mouth	Grab samples, continuous flow station	-120.7278	47.6795
45CK01.0	Chiwaukum Cr abv campground	Grab samples	-120.7386	47.6880
45CR00.1	Chumstick irrigation return nr mouth	Grab samples, instantaneous flow	-120.6488	47.6047
45CW00.5	Chiwawa Cr nr mouth	Grab samples, instantaneous flow	-120.6475	47.7880
45FL00.3	Fish Lake Run nr mouth	Grab samples, instantaneous flow	-120.6946	47.8181
45IC00.1	Icicle Cr at mouth	Grab samples, continuous flow station	-120.6613	47.5789
45LR01.2	Little Wenatchee R nr mouth	Grab samples, instantaneous flow	-120.8370	47.8341
45NC00.7	Nason Cr nr mouth	Grab samples, continuous flow station	-120.7143	47.8020
45NC01.2	Nason Cr abv campground	Grab samples	-120.7134	47.7959
45WDA	Chiwawa irrigation return A	Grab samples, instantaneous flow	-120.6632	47.7376
45WDB	Chiwawa irrigation return B	Grab samples, instantaneous flow	-120.6614	47.7436
45WH01.9	White R nr mouth	Grab samples, instantaneous flow	-120.8356	47.8472
45WR26.2	Wenatchee R at Leavenworth	Grab samples, instantaneous flow, continuous diel data	-120.6736	47.5777
45WR30.7	Wenatchee R at Tumwater Dam	Grab samples	-120.7215	47.6163
45WR35.4	Wenatchee R nr Leavenworth	Grab samples, instantaneous flow, continuous diel data	-120.7331	47.6762
45WR41.8	Wenatchee R south of Plain at RR Br	Grab samples, continuous diel data	-120.6615	47.7182
45WR46.2	Wenatchee R nr Plain	Grab samples, continuous diel data	-120.6605	47.7673
45WR53.9	Wenatchee R blw lake outlet	Grab samples, continuous flow station, continuous diel data	-120.7114	47.8107
45WR54.0	Wenatchee R at state park boat launch	Grab samples, continuous diel data	-120.7245	47.8079

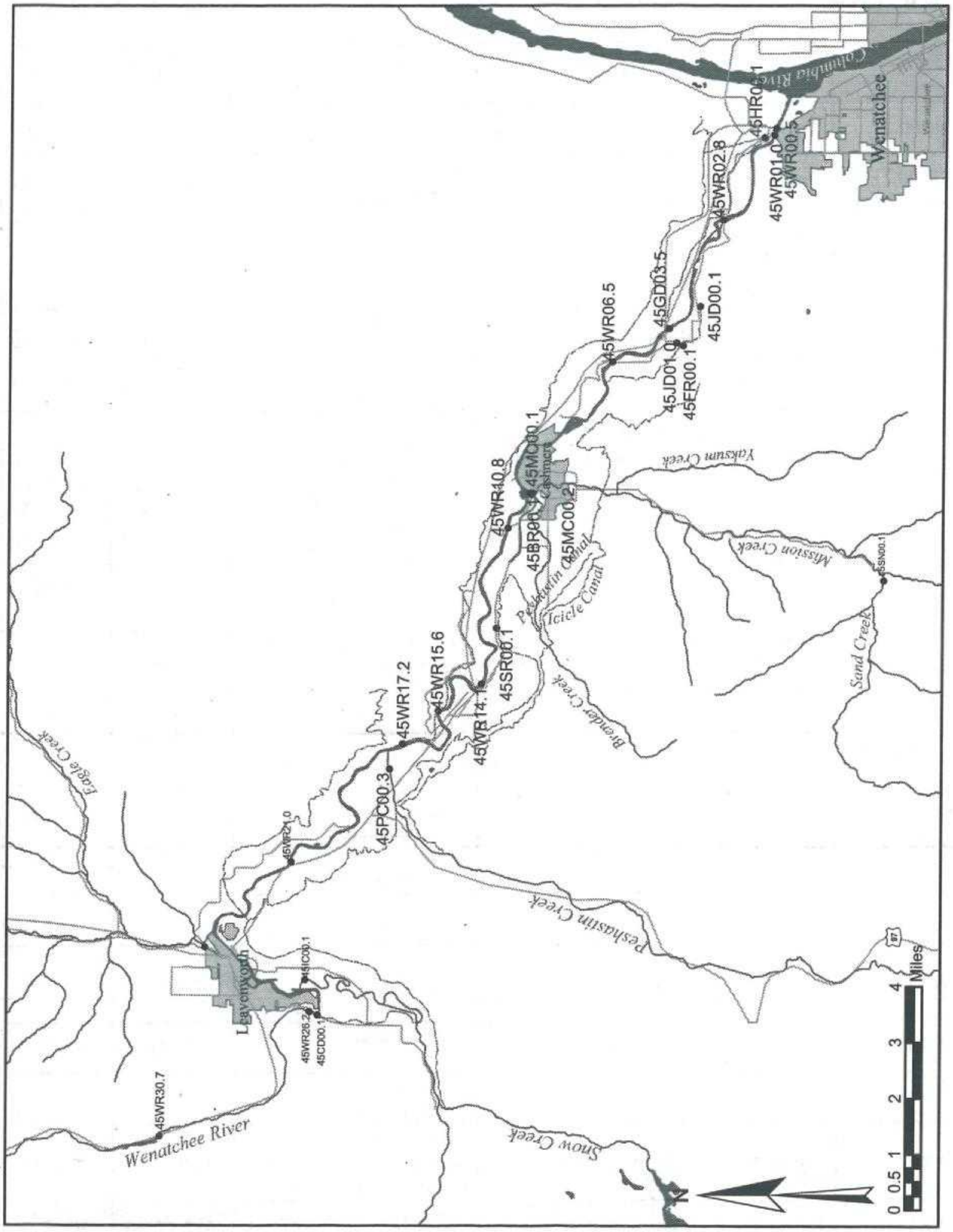


Figure 3. Lower mainstem Wenatchee River sampling stations for the 2002-03 TMDL study.

Table 7. Lower mainstem Wenatchee River sample site, identification, description, and location.

Station ID (includes RM)	Station Name	Type of Field Measurement	Longitude	Latitude
45BR00.1	Brender Cr nr Cashmere	Grab samples, instantaneous flow	-120.4754	47.5214
45CD00.1	Cascade Orchards irrigation return	Grab samples, continuous flow station	-120.6749	47.5756
45CR00.1	Chumstick irrigation return nr mouth	Grab samples, instantaneous flow	-120.6488	47.6047
45FR00.1	Icicle irrigation return at Fairview Cyn Rd	Grab samples, instantaneous flow	-120.4174	47.4843
45GD03.5	Gunn Ditch at diversion	Grab samples, instantaneous flow	-120.4119	47.4862
45HR00.1	Highline Canal return at mouth	Grab samples, continuous flow station	-120.3390	47.4619
45IC00.1	Icicle Cr at mouth	Grab samples, continuous flow station	-120.6613	47.5789
45JD00.1	Jones Shotwell Ditch at mouth	Grab samples, instantaneous flow	-120.4035	47.4781
45JD01.0	Jones Shotwell Ditch upstream of mouth	Grab samples, instantaneous flow	-120.4185	47.4826
45MC00.1	Mission Cr nr mouth blw Brender	Grab samples, continuous flow station	-120.4748	47.5219
45MC00.2	Mission Cr nr Cashmere	Grab samples, continuous flow station	-120.4748	47.5212
45PC00.3	Peshastin Cr nr mouth	Grab samples, continuous flow station	-120.5804	47.5573
45SR00.1	Stines Hill Icicle irrigation return	Grab samples, instantaneous flow	-120.5265	47.5301
45WR00.5	Wenatchee R at Wenatchee	Grab samples, continuous diel data	-120.3354	47.4589
45WR01.0	Wenatchee R upstream of mouth	Grab samples, continuous diel data	-120.3383	47.4594
45WR02.8	Wenatchee R at Sleepy Hollow Br	Grab samples	-120.3705	47.4722
45WR06.5	Wenatchee R at Old Monitor Br	Grab samples, continuous diel data	-120.4247	47.5010
45WR10.8	Wenatchee R nr Cashmere	Grab samples, continuous diel data	-120.4882	47.5275
45WR14.1	Wenatchee R abv Olalla	Grab samples, continuous diel data	-120.5479	47.5338
45WR15.6	Wenatchee R at PUD rearing pond return	Grab samples	-120.5582	47.5449
45WR17.2	Wenatchee R at Highline diversion	Grab samples, continuous diel data	-120.5708	47.5540
45WR21.0	Wenatchee R abv Peshastin	Grab samples, continuous diel data	-120.6162	47.5828
45WR26.2	Wenatchee R at Leavenworth	Grab samples, instantaneous flow, continuous diel data	-120.6736	47.5777
45WR30.7	Wenatchee R at Tumwater Dam	Grab samples	-120.7215	47.6163

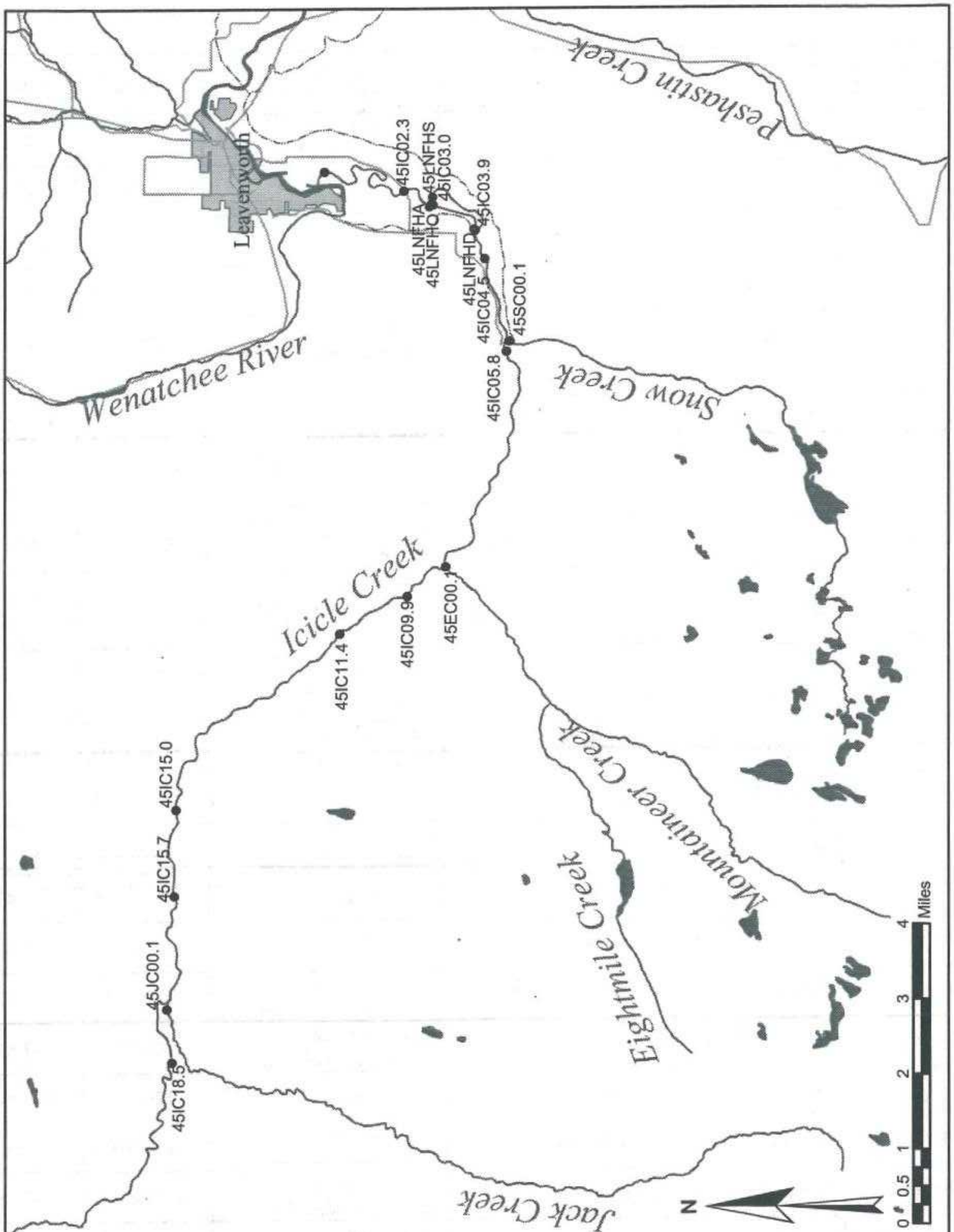


Figure 4. Icicle Creek sampling stations for the 2002-03 TMDL study.

Table 8. Icicle Creek sample site identification, description, and location.

Station ID (includes RM)	Station Name	Type of Field Measurement	Longitude	Latitude
45EC00.1	Eightmile Cr nr mouth	Grab samples, instantaneous flow	-120.7739	47.5553
45IC00.1	Icicle Cr at mouth	Grab samples, continuous flow station, continuous diel data	-120.6613	47.5789
45IC02.3	Icicle Cr nr Leavenworth	Grab samples, continuous diel data	-120.6668	47.5636
45IC03.0	Icicle Cr at hatchery	Grab samples, instantaneous flow	-120.6685	47.5581
45IC03.9	Icicle Cr at LNFH old channel headgate	Grab samples, continuous flow station, continuous diel data	-120.6780	47.5499
45IC04.5	Icicle Cr abv LNFH diversion	Grab samples, continuous flow station	-120.6861	47.5480
45IC05.8	Icicle Cr abv Snow Cr	Grab samples	-120.7125	47.5438
45IC09.9	Icicle Cr abv Eightmile Cr	Grab samples, continuous diel data	-120.7823	47.5627
45IC11.4	Icicle Cr blw 4th of July Cr	Grab samples	-120.7930	47.5756
45IC15.0	Icicle Cr at Ida Cr Campground	Grab samples	-120.8431	47.6069
45IC15.7	Icicle Cr at Doctor Bob Br	Grab samples	-120.8679	47.6071
45IC18.5	Icicle Cr abv Jack Cr	Grab samples, continuous diel data	-120.9154	47.6075
45JC00.1	Jack Cr nr mouth	Grab samples, instantaneous flow	-120.9002	47.6085
45LNFHA	LNFH abatement pond	Grab samples, continuous flow station	-120.6713	47.5587
45LNFHD	LNFH return ditch	Grab samples, instantaneous flow	-120.6777	47.5502
45LNFHO	LNFH outlet	Grab samples, continuous flow station	-120.6707	47.5584
45LNFHS	Icicle Cr main channel blw LNFH spillway	Grab samples	-120.6708	47.5580
45SC00.1	Snow Creek nr mouth	Grab samples, instantaneous flow	-120.7096	47.5432

Sampling and Quality Control Procedures

All water samples for laboratory analysis were collected in pre-cleaned containers supplied by Ecology's Manchester Environmental Laboratory (MEL), except dissolved organic carbon, dissolved total phosphorus, and orthophosphate which were collected in a syringe and filtered into a pre-cleaned container. The syringe was rinsed with ambient water at each sampling site three times before filtering. All samples for laboratory analysis were preserved as specified by MEL (2000) and delivered to MEL within 24 hours of collection. Laboratory analyses listed in Table 4 were performed in accordance with MEL (2000).

Field sampling and measurement protocols followed those specified in WAS (1993) for *in situ* temperature, DO, pH, and specific conductance (Hydrolab® multi-parameter meters) and for DO Winkler titrations. All meters were calibrated and post-calibrated per manufacturer's instructions.

Effluent samples from the point sources were collected in pre-cleaned ISCO 24-hour composite samplers. Effluent sampling was conducted according to standard operating procedures for Class II inspections by Ecology as documented in Glenn (1994). Appendix B contains a summary of the field notes from the point source sampling describing the sample collection and field measurements. Groundwater data collected by Ecology followed protocols defined in Garrigues (1999).

Replicate samples were collected to assess total field and laboratory variation. Blanks were also used to assess possible sample contamination. Replicate and blank samples were introduced in the field and submitted "blind" with the routine batches of samples to the laboratory.

Phytoplankton samples were preserved with 1% Lugol's solution immediately after collection and sent to Jim Sweet, Aquatic Analysts, Wilsonville, Oregon, for plankton analyses.

Data Quality Results

Quality Assurance Objectives

Data collected for this Wenatchee River TMDL Study were evaluated to determine whether data quality assurance/quality control (QA/QC) objectives for the project were met. Water quality data QA/QC objectives for precision, bias, and accuracy are described in Table 5.

Sample Quality Assurance

QA/QC for Samples

Field Sampling

Field sampling protocols followed those specified in WAS (1993). Field QC requirements include the use of field replicates and field blanks to assess total precision and field bias, respectively.

Laboratory

MEL was used for all laboratory analyses. Laboratory data were generated according to QA/QC procedures described in MEL (2000). MEL prepared and submitted QA memos to Ecology's Environmental Assessment Program for each sampling survey. Each memo summarized the QC procedures and results for sample transport and storage, sample holding times, and instrument calibration. The memo also included a QA summary of check standards, matrix spikes, method blanks (used to check for analytical bias), and lab-split samples (used to check for analytical precision).

With few exceptions, all samples were received in good condition and were properly preserved, as necessary. The temperature of the shipping coolers was between proper ranges of 2°C - 6°C for all sample shipments except two coolers received at MEL on July 25, 2002. On that day, one cooler had an ambient temperature of 7°C, and another cooler had an ambient temperature of 8°C; however, the samples for that date were not qualified for being out of range.

Holding times were violated at times throughout the project because of delayed transport problems or because the samples were held too long at MEL before analysis. MEL qualified as estimates all individual samples that were analyzed beyond holding times with a "J".

Instrument calibration and control checks were all within control limits for the project. Lower reporting limit objectives were met for all parameters except total phosphorus (TP) for the November 12 and 13, 2002 survey (TP on that survey had a reporting limit of 10 ug/L instead of 3 ug/L). Results not detected at or above the reporting limits listed in Table 5 were qualified by MEL with a "U". Data below the reporting limit were excluded from consideration in determining analytical and total precision (see below).

For the most part, data quality for this project met all lab QA/QC criteria as determined by MEL. Individual exceptions that caused the results to be qualified as an estimate were marked by MEL with a "J" qualifier in the data tables. All qualifications will be taken into consideration for the purpose of data analysis. Data precision, bias, and accuracy for all parameters are compared separately below to the project data quality objectives listed in Table 5.

Precision

Analytical Precision

Analytical laboratory precision was determined separately in order to account for its contribution to overall variability. Laboratory split samples were analyzed at least once per batch (or about 10% of the total) to assess analytical precision. A pooled relative standard deviation (%RSD) was calculated for each parameter using lab-split results greater than reporting limits. %RSD was calculated by first calculating a pooled standard deviation as the square of the sum of the squared differences divided by two times the number of pairs. Then the pooled standard deviation was divided by the mean of the replicate measurements and then multiplied by 100 for the %RSD. Higher %RSD is expected for values that are close to their reporting limit (e.g., the %RSD for replicate samples with results of 1 and 2 is 47%, whereas the %RSD for replicate results of 100 and 101 is 0.7%, with each having a difference of 1).

Because higher %RSD is expected near the reporting limit, two tiers were also evaluated; lab-split results less than five times the reporting limit were considered separately from lab-splits results equal to or more than five times the reporting limit (for FC bacteria, the two tiers were less than 50 and greater than or equal to 50 cfu/100mL). The %RSD in the upper tier was compared to the target precision objective for each parameter. Analytical precision for all parameters was below the target precision objectives for both years. Results are listed in Table 9.

Table 9. Lab precision results. Results at the detection limit were excluded from consideration.

Parameter	Target Precision %RSD	Average %RSD for samples <5X reporting limit (number of duplicate pairs)	Average %RSD for samples ≥5X reporting limit (number of duplicate pairs)
Alkalinity	<10	3.3 (21)	0.7 (24)
Ammonia-Nitrogen	<10	0.0 (1)	0.8 (2)
BOD	<25	0.0 (2)	10.6 (3)
Chloride	<5	6.7 (13)	0.3 (11)
Chlorophyll	<20	6.0 (2)	6.5 (17)
Dissolved Organic Carbon	<10	8.8 (5)	2.4 (2)
Fecal coliform[1]	<25	35.6 (19)	15.5 (2)
Nitrite-Nitrate Nitrogen	<10	2.0 (10)	1.8 (11)
Orthophosphate	<10	6.5 (16)	8.1 (5)
Total Dissolved Solids	<10	all samples >5X reporting limit	1.9 (35)
Total Nonvolatile Suspended Solids	<10	11.3 (7)	4.6 (4)
Total Organic Carbon	<10	7.0 (19)	1.4 (4)
Total Phosphorus	<10	10.4 (20)	4.4 (7)
Total Persulfate Nitrogen	<10	12.3 (14)	6.2 (13)
Total Suspended Solids	<10	0.0 (11)	3.9 (8)
Turbidity	<10	6.3 (13)	1.7 (6)

[1]Bacteria duplicates are split into samples <50cfu/100mL and ≥50cfu/100 mL

Total Precision

Field replicate samples were collected for at least 10% of the total general chemistry samples and at least 20% of the total microbiology samples in order to assess total precision (i.e., total variation) for field samples. As was done for the lab precision evaluation, two tiers were also evaluated for total precision: field-replicate results less than five times the reporting limit and field-replicate results equal to or more than five times the reporting limit (for FC bacteria, the two tiers were less than 50 and greater than or equal to 50 cfu/100mL). A pooled relative standard deviation (%RSD) was calculated for each parameter using field replicate results greater than reporting limits. Results are listed in Table 10.

Table 10. Total precision (field + lab) results. Results at the detection limit were excluded from consideration.

Parameter	Target Precision %RSD	Average %RSD for samples <5X reporting limit (number of duplicate pairs)	Average %RSD for samples ≥5X reporting limit (number of duplicate pairs)
Alkalinity	<10	1.8 (19)	1.9(23)
Ammonia-Nitrogen	<10	11.9 (5)	2.5 (1)
Chloride	<5	5.6 (11)	4.9 (18)
Chlorophyll	<20	12.3 (1)	13.6 (19)
Dissolved Organic Carbon	<10	all samples >5X reporting limit	9.7 (7)
Fecal Coliform[1]	<25	25.3 (13)	15.1 (1)
Nitrite-Nitrate Nitrogen	<10	2.2 (13)	4.5 (11)
Orthophosphate	<10	15.9 (26)	0.4 (4)
Total Dissolved Solids	<10	all samples >5X reporting limit	5.4 (26)
Total Nonvolatile Suspended Solids	<10	20.0 (4)	8.7 (4)
Total Organic Carbon	<10	10.2 (21)	all samples <5X reporting limit
Total Phosphorus	<10	15.1 (17)	5.7 (6)
Total Persulfate Nitrogen	<10	16.7 (14)	5.2 (17)
Total Suspended Solids	<10	12.0 (12)	22.9 (9)
Turbidity	<10	13.6 (16)	12.3 (9)

[1]Bacteria duplicates are split into samples <50cfu/100mL and ≥50cfu/100 mL

Total precision %RSD in the upper tier was compared to the target precision. As expected, %RSD for field replicates was generally higher than that for lab-splits because %RSD for field replicates is a measurement of total variability, including both field and analytical variability.

The %RSD for all parameters met the target precision objectives except for total suspended solids and turbidity. The analytical precision for total suspended solids and turbidity was very good so most of the variability appears to be field variability. Total suspended solid concentrations are inherently variable because of patchy distributions in the environment and intermittent discharge. Total suspended solids and turbidity data were not qualified, but the data variability for the two parameters will be taken into consideration when using the data for modeling and other analyses, and for interpreting results.

Analytical Bias

Analytical bias was evaluated using method blanks, laboratory check standards, and matrix spikes. Each of these control samples were run once per batch or every 20 samples. Method blanks for all parameters were below reporting limits for the entire project with the following exceptions:

- One method blank sample run with a batch of chlorophyll *a* samples collected on August 27, 2002 had a value slightly above the reporting limit. The entire batch was qualified as an estimate (denoted by "J") due to other instrumentation problems, however.
- Over one third of the method blanks samples for total dissolved solids (TDS) batch analyses were slightly above reporting limits (1-3 mg/L; reporting limit =1 mg/L). There were no qualifications of TDS data.

Pooled laboratory check standard deviations and matrix spike recoveries were compared to the target maximum bias for each applicable parameter in Table 11. Analytical bias was considered acceptable for all of the parameters.

Table 11. Pooled analytical bias results by parameter.

Parameter	Target Bias (maximum % deviation from true value)	Pooled % recovery of matrix spike addition to sample	Pooled % deviation from true value of laboratory control sample
Alkalinity	5	1.6	2.5
Ammonia-Nitrogen	5	1.2	4.7
Chloride	5	5.2	2.7
Chlorophyll	10	N/A	3.3
Dissolved Organic Carbon	10	8.1	5.7
Nitrite-Nitrate Nitrogen	5	2.6	2.0
Orthophosphate	5	2.4	5.5
Total Dissolved Solids	10	N/A	1.5
Total Organic Carbon	10	4.8	4.8
Total Phosphorus	5	2.1	4.7
Total Persulfate Nitrogen	10	4.7	3.3
Total Suspended Solids	10	N/A	2.4
Turbidity	10	N/A	1.2

Field Bias

Field-blank samples were submitted to Manchester Laboratory blindly to determine bias from contamination in the field. Results are presented in Table 12. Field-blank contamination was suspected when measured values exceeded the corresponding reporting limits. With the exception of three samples (see below), all submitted field-blank measurement values were below reporting limits.

NO2-NO3 was measured above the reporting limit in a field-blank sample from July 24, 2002. A review of laboratory QA/QC for NO_2-NO_3 on that date showed no laboratory bias or contamination. Since the measured value of the field blank was just slightly above the reporting limit, no correction or qualification was made to NO_2-NO_3 results for that date.

Total organic carbon (TOC) and dissolved organic carbon (DOC) were measured above their reporting limits in field-blank samples submitted on September 25, 2002. A review of laboratory QA/QC for TOC and DOC on that date showed no laboratory bias or contamination. Other samples with measurable results above the reporting limits from that date did not have evidence of contamination (i.e., sample results were below the field-blank results). In reviewing all field and laboratory quality control data, it does not appear that there was any contamination or bias in either the sampling or analytical procedures; therefore, no qualifications or corrections were made for TOC or DOC results from that date.

Table 12. Field-blank results. Results qualified with "U" or "UJ" were not detected at the reporting limit.

Parameter	Date	Result		
Alkalinity	07/24/02	5	mg/L	U
	08/28/02	5	mg/L	U
	09/25/02	5	mg/L	U
Ammonia-Nitrogen	07/24/02	0.01	mg/L	U
	08/28/02	0.01	mg/L	U
	09/25/02	0.01	mg/L	U
Chlorides	07/24/02	0.1	mg/L	U
	08/28/02	0.1	mg/L	U
	09/25/02	0.1	mg/L	UJ
Chlorophyll	07/24/02	0.05	ug/L	U
	08/28/02	0.05	ug/L	UJ
	09/25/02	0.05	ug/L	U
Dissolved Organic Carbon	07/24/02	1	mg/L	U
	08/28/02	1	mg/L	U
	09/25/02	3.7	mg/L	
E. coli	07/24/02	1	#/100 mL	U
	08/28/02	8	#/100 mL	U
	09/25/02	3	#/100 mL	U
Fecal Coliform Bacteria	07/24/02	1	#/100 mL	U
	08/28/02	8	#/100 mL	U
	09/25/02	3	#/100 mL	U
Nitrite-Nitrate Nitrogen	07/24/02	0.012	mg/L	
	08/28/02	0.01	mg/L	UJ
	09/25/02	0.01	mg/L	U
Orthophosphate	07/24/02	0.003	mg/L	U
	08/28/02	0.003	mg/L	U
	09/25/02	0.003	mg/L	U
Total Dissolved Solids	07/24/02	1.0	mg/L	U
	08/28/02	1.0	mg/L	U
Total Non-Volatile Suspended Solids	07/24/02	0.010	mg/L	U
	08/28/02	0.010	mg/L	U
Total Organic Carbon	07/24/02	1.0	mg/L	U
	08/28/02	1.0	mg/L	U
	09/25/02	3.7	mg/L	
Total Persulfate Nitrogen	07/24/02	0.025	mg/L	U
	08/28/02	0.025	mg/L	U
	09/25/02	0.025	mg/L	U
Total Phosphorus (TP), Low-level	07/24/02	3	ug/L	U
	08/28/02	3	ug/L	U
	9/25/02	3	ug/L	U
TP, Low-level – dissolved	07/24/02	3	ug/L	U
	08/28/02	3	ug/L	U
Total Suspended Solids	07/24/02	1	mg/L	U
	08/28/02	1	mg/L	U
	09/25/02	1	mg/L	U
Turbidity	07/24/02	0.5	NTU	U
	08/28/02	0.5	NTU	U
	09/25/02	0.5	NTU	U

Accuracy

Accuracy is defined as two times the precision %RSD plus the bias. The higher-tier %RSD (except TOC) and the higher of the analytical biases (matrix spike recoveries and lab control samples deviation) were used to calculate the accuracy. Accuracy targets and results are presented in Table 13. All accuracy targets were met for each parameter except total suspended solids (TSS). The high variability associated with all TSS data will be taken into consideration when using the data for modeling, analyses, and interpretation of results.

Table 13. Accuracy results compared to target accuracy objectives.

Parameter	Target Accuracy (maximum % deviation from true value)	Observed accuracy (calculated as 2 X precision %RSD plus bias)
Alkalinity	25	6.3
Ammonia-Nitrogen	25	9.7
Chloride	15	15
Chlorophyll	50	30.5
Dissolved Organic Carbon	30	27.5
Nitrite-Nitrate Nitrogen	25	11.6
Orthophosphate	25	6.3
Total Dissolved Solids	30	12.3
Total Organic Carbon	30	25.2
Total Phosphorus	25	16.1
Total Persulfate Nitrogen	30	15.1
Total Suspended Solids	30	48.2
Turbidity	30	25.8

Field Measurement Quality Assurance

Field measurement protocols followed those specified in WAS (1993) for dissolved oxygen (DO) (Winkler titration), streamflow (Marsh-McBirney, 2000), and *in situ* temperature, DO, pH, and specific conductance (Hydrolab® multi-parameter meters).

Hydrolab® meters were used for taking instantaneous measurements and to capture continuous measurements. Meters were pre- and post-calibrated for pH, DO, and conductivity. The manufacturer's instructions were followed for pH and conductivity calibration, using pH 7 and pH 10 low-ionic buffer solutions and 100 umhos/cm conductivity standard solution. The DO sensor was pre-calibrated to theoretical water-saturated air, in accordance with manufacturer's instructions. Winkler field samples were collected daily for use as DO check standards. If necessary, Winkler DO measurements were used to adjust meter data (see below).

Precision

Replicate or duplicate measurements were not taken for instantaneous or continuous field measurements so there was not an assessment of precision for these measurements. All measurements made with meters were taken *in situ,* and the meter was allowed to equilibrate to a stable reading as in the case for an instantaneous reading, or was given a two-minute equilibration period before a reading was recorded as in the case for a continuous reading. Continuous readings were generally 30 minutes apart and were conducted for 12 to 24 hours or longer.

Bias

Instantaneous Measurement Bias

The average difference of post-calibration pH readings was 0.07 standard pH units (s.u.) with a standard deviation of 0.1 s.u. The pooled bias for all of the post-calibration instantaneous pH readings was 0.09 s.u. (the target bias was less than 0.1 s.u.). All instantaneous pH readings were considered acceptable except five pH readings from July 21, 2003 which were qualified as estimates due to a problem with the meter that morning.

Post-calibration checks for instantaneous conductivity measurements had a pooled %RSD bias of 3.4%, well under the target maximum bias of 5%. All instantaneous conductivity measurements were considered acceptable for use without qualification.

Hydrolab® instantaneous DO data was compared to Winkler check standards to assess bias. In most cases, there was a slight adjustment (correction factor) applied to the meter DO data, and there was no qualification designated.

The pooled standard deviation for instantaneous DO data was 0.16 mg/L with a pooled %RSD of 1.45%, well below the target maximum bias of 5%. For several sampling dates, instantaneous DO results were rejected or qualified due to poor correlation between Hydrolab and Winkler values, or malfunctioning equipment.

Some of the Hydrolab instantaneous DO data were rejected for the following dates:

- June 25, 2002 (1 value)
- July 23, 2002 (2 values)
- September 23, 2002 (3 values)
- January 7, 2003 (1 value)

In addition, for the following sampling dates, some or all of the instantaneous DO results were corrected but qualified as estimates (denoted with "J") due to poor correlation between Hydrolab and Winkler values:

- June 25, 2002 (7 values)
- July 22-23, 2002 (11 values)
- August 5, 2002 (2 values)

- August 27-28, 2002 (3 values)
- September 10, 2002 (2 values)
- September 23-25, 2002 (22 values)
- October 9, 2002 (17 values)
- October 21-22, 2002 (20 values)
- December 3, 2002 (1 value)

Other than the noted exceptions, all other DO data were considered acceptable for use.

Continuous Measurement Bias

The average difference of post-calibration pH readings for continuous Hydrolab® meters was 0.08 s.u. (standard deviation of 0.10 s.u.). The pooled bias for all of the post-calibration continuous pH readings was 0.09 s.u. (the target maximum bias was 0.1 s.u.). All continuous pH readings were considered acceptable except pH readings from Hydrolab® meter #21 used on April 7-10, 2003 which were qualified because of poor post-calibration.

Post-calibration checks for continuous conductivity measurements had a pooled %RSD bias of 5%, meeting the target maximum bias of 5%. All conductivity measurements were considered acceptable for use without qualification.

Quality assurance (QA) of the continuous DO data was conducted for nearly 60 continuous data profiles recorded with Hydrolab® meters for the project. The QA/QC was verified a variety of ways including the following QA checks:

1. Pre-calibration of DO prior to deployment.
2. Field measurements of DO at the beginning, during, and end time of deployment with either Winkler's or another calibrated DO meter.
3. Post calibration of the DO meter.
4. Plotting measured DO values against calculated saturated values as a bias check, particularly useful for measured DO data from unproductive areas, but a rough bias check for productive areas as well.

Accuracy

For field measurements, target objectives for accuracy were set for velocity and temperature. Both accuracy targets are from manufacturers specifications for the respective instruments (velocity meter and thermometer). Instruments are factory calibrated and were considered to be performing within the specified published accuracies during the field season.

Conclusion

Overall, the data collected by Ecology for this project met the data quality objectives. The QA and QC review suggests that the Ecology data are of good quality and are properly qualified.

Wenatchee River TMDL Data

All laboratory and field data collected for the Wenatchee River TMDL are loaded into Ecology's Environmental Information Management (EIM) database and are available on-line from the Ecology website at: www.ecy.wa.gov/programs/eap/env-info.html. Several query options are available. The study identification (study ID) designation is "WENRTMDL" and the study name is "Wenatchee River TMDL".

Additional data collected by Ecology's Freshwater Monitoring Unit (FMU) are used in this TMDL analysis and are also available on-line at the above EIM website. The study ID designation for these data is AMS001. Table 14 shows the FMU stations used in support of the Wenatchee River TMDL effort.

Table 14. Ecology's Freshwater Monitoring Unit stations used in the Wenatchee TMDL study and the project station equivalent.

FMU Station	Wenatchee TMDL Project station equivalent	Site Description
45D070	45BR00.4	Brender Creek above mouth
45C070	45CS00.5	Chumstick Creek near mouth
45C060	45CS00.1	Chumstick Creek above mouth
45Q060	45EG00.3	Eagle Creek above mouth
45E070	45MC00.2	Mission Creek near Cashmere
45R050	45NN00.2	No Name Creek at Mill Road
45A070	45WR00.5	Wenatchee River near mouth
45A110	45WR35.4	Wenatchee River near Leavenworth (Tumwater canyon Hwy 2 bridge)

Dissolved Oxygen, pH, and Phosphorus TMDL

The Wenatchee River and Icicle Creek were on the 1998 303(d) list for pH and dissolved oxygen (DO) (see Table 1). The 1998 303(d) listings were the result of sampling by Ecology and the Chelan County Conservation District from 1992 through 1997.

This current Wenatchee River Basin TMDL study focused on the Wenatchee River and Icicle Creek in 2002 and 2003.

Table 15 shows the 2004 303(d) listings for impaired waters in WRIA 45 due to dissolved oxygen (DO) and pH water quality standard exceedances. A majority of the data used for the 2004 DO and pH listings were generated by the TMDL surveys in 2002-03 discussed in this report. Mission, No Name, Van, and Brender creeks (as well as the Peshastin Irrigation management return flow) are also on the 303(d) list for DO and/or pH, but were addressed in the Wenatchee River Basin Bacteria TMDL (Carroll and O'Neal, 2005). Therefore, all of the currently listed (i.e., impaired) waters for DO and pH in WRIA 45 have been evaluated.

Table 15. Streams on the 2004 303(d) list of impaired waterbodies for dissolved oxygen and pH water quality standard violations in the Wenatchee basin.

Stream	303(d) listing ID Number	Water Course Number	Parameter	Location
Icicle Creek	8417*	KN36FW	pH	T24N, R17E, Section 24
	8416*	KN36FW	Dissolved Oxygen	T24N, R17E, Section 24
Wenatchee River	10702*	HM20EV	pH	T23N, R20E, Section 28
	10705*	HM20EV	Dissolved Oxygen	T25N, R17E, Section 9
	41269	HM20EV	pH	T23N, R19E, Section 11
Mission Creek	34799	DQ04NW	pH	T23N, R19E, Section 4
	11282	DQ04NW	pH	T23N, R19E, Section 5
No Name Creek	41819	UNK000	pH	T23N, R19E, Section 5
Peshastin Irrigation return	41823	DQ04NW	pH	T23N, R19E, Section 4
Van Creek	41834	VF45OQ	pH	T25N, R18E, Section 24
Brender Creek	8406*	FB41UG	Dissolved Oxygen	T23N, R19E, Section 5

* = Also listed on the 1996 and 1998 303(d) Lists.

Periphyton (attached algae) plays an important role in the dynamics of pH and DO processes in the Wenatchee River and Icicle Creek. In addition, phosphorus and nitrogen are important parameters because of their role as nutrients for the growth of periphyton in the waterways (see below).

Water Quality Concerns for Fisheries

A Wenatchee River basin limiting factors analysis for salmon, steelhead, and bull trout (Andonaegui, 2001) identified factors affecting natural salmonid production in the Wenatchee River basin. The report summarizes in detail fisheries use of streams in the Wenatchee River basin. Currently, spring chinook, summer chinook, steelhead (rainbow), sockeye, and bull trout use the Wenatchee River and Icicle Creek for spawning, rearing, and/or migration. Summer chinook and steelhead use the lower Wenatchee River (below river mile (RM) 25.6) for spawning. Temperature and fine sediment were identified as water quality limiting factors in the Wenatchee basin; however, pH and DO were noted to affect salmonid habitat quality and currently to be out of compliance with state water quality standards. The state water quality standards were established to protect fisheries and wildlife, as well as public health and enjoyment. Compliance with these standards will enhance the propagation and protection of fisheries in the basin.

Applicable Criteria

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state.

Beneficial Uses and Classifications

The Wenatchee River is a tributary to the Class A portion of the Columbia River (WAC 173-201A-030). Consequently, the Wenatchee River from its mouth to the Forest Service boundary is considered a Class A, "excellent," waterbody. Icicle Creek is considered a Class A waterbody from its confluence with the mainstem Wenatchee River to the Wenatchee National Forest boundary. From the Wenatchee National Forest boundary to their headwaters, the Wenatchee River and Icicle Creek are considered Class AA, "extraordinary," waterbodies.

Characteristic uses for Class A waterbodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation. Characteristic uses for Class AA are considered identical to Class A characteristic uses.

Numeric criteria for specific water quality parameters are intended to protect designated uses. However, criteria are more stringent in Class AA waters such that the class shall markedly and uniformly exceed the requirements for all, or substantially all, uses. The criteria for dissolved oxygen, pH, and nutrients (nitrogen and phosphorus) are presented below.

Dissolved Oxygen

- For Class A Waters: *dissolved oxygen shall exceed 8.0 mg/L.*
- For Class AA waters: *dissolved oxygen shall exceed 9.5 mg/L.*

pH

- For Class A Waters: *pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.5 units.*
- For Class AA Waters: *pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.2 units.*

Nutrients (Nitrogen and Phosphorus)

Nitrogen and phosphorus are essential nutrients for plant growth and aquatic community health. However, when there is an overabundance of nutrients, aquatic plant growth can become over-stimulated, a process called eutrophication. If natural reaeration processes cannot compensate for plant respiration and production in areas affected by eutrophication, dissolved oxygen becomes under-saturated at night and over-saturated during the day, and hydrogen ion (pH) concentrations become over-saturated at night and under-saturated during the day. These diel (i.e., day to night) swings can be harmful to macroinvertebrates and fish.

Washington State water quality standards do not have numeric nutrient (nitrogen and phosphorus) criteria for streams. However, Chapter 173-201A contains a narrative criterion that states:

> *"Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department."*

This narrative criterion applies to nitrogen and phosphorus.

Natural Causes and Anti-degradation

Other sections of the water quality standards (in Chapter 173-201A WAC) are pertinent to the Wenatchee TMDL. Chapter 173-201A-070, a section on anti-degradation, states that existing beneficial uses shall be maintained and protected, and no further degradation allowed. The section goes on to state that: *"Whenever the natural conditions of said waters are of lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria."*

This recognizes that natural conditions do not meet numeric criteria at all times. In cases where DO concentrations are lower than the numeric criterion due to natural conditions, Ecology TMDL policy (Ecology, 1996) allows up to a 0.2 mg/L degradation of DO below natural conditions from cumulative human impacts (i.e., 0.2 mg/L is considered the first detectable change in DO). There is no further allowable pH degradation to waters that exceed the pH criteria due to natural conditions.

Future Changes of the Water Quality Standards

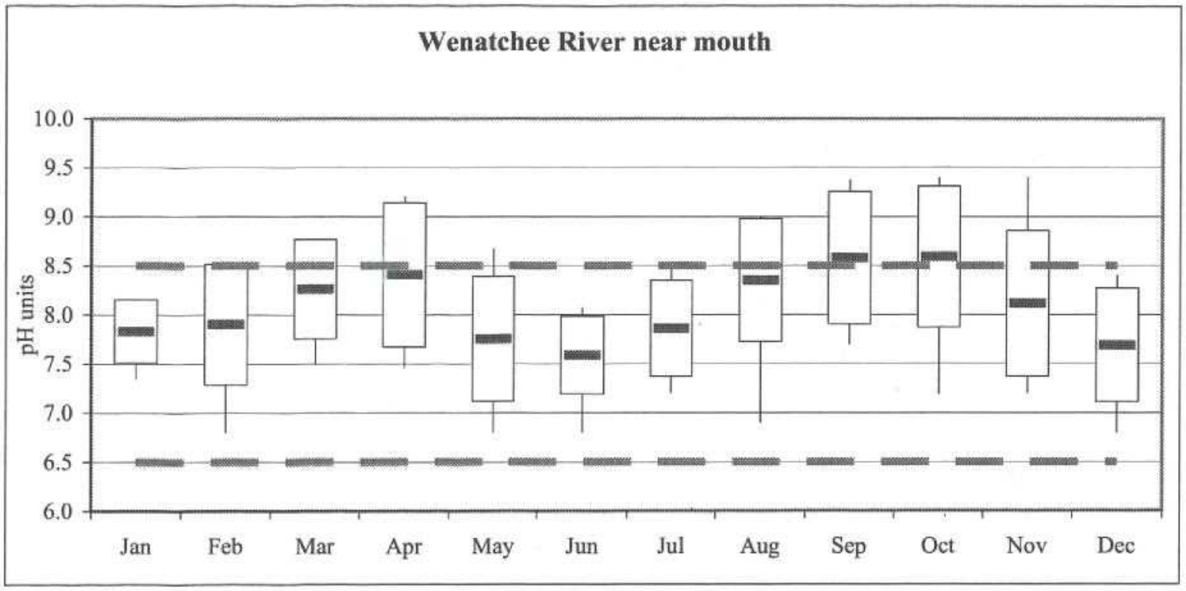
The water quality standards are currently under revision. Changes have been adopted and are awaiting EPA approval for DO, microbial pathogens (currently represented by the fecal coliform group), and temperature. Fresh waters will be classified by use (such as fish habitat, swimming and water supply), rather than by class (AA, A, B, C and Lake classes), to allow the standards to be more tailored to specific waterbody uses. The proposed new standards may pose some changes to the numeric criteria for fecal coliform bacteria, DO, and pH in the Wenatchee Basin, depending on the final designated uses of specific areas.

Proposed new standards can be found on the Ecology website: www.ecy.wa.gov/programs/wq/swqs/index.html. The new standards are not expected to be approved by EPA before the completion of this TMDL study. Post-TMDL assessments may be compared to the existing criteria and any new criteria that are approved.

Seasonal Variation

Seasonal variation of DO and pH is best illustrated by an analysis of the two long-term Ecology ambient monitoring stations in the basin. Figure 5 shows box plots of monthly pH measurements for the Wenatchee River at the mouth and above Tumwater Canyon from 1993 to 2004 (Ecology ambient monitoring stations are near the TMDL study stations 45WR00.5 in Figure 3 and 45WR35.4 in Figure 2). The instantaneous pH measurements did not necessarily capture the daily maximum or minimum because measurements were made at different times of the day. There are two clear seasons of excursions at the mouth of the Wenatchee River, with 18 out of 30 exceedances occurring between August and November, and the rest occurring between March and May. These two seasons encompass the growing season when light is more available and water temperatures are warmer in the Wenatchee River. High pH excursions result from periphyton growth (i.e., productivity of the algae attached to the substrate).

Periphyton growth is divided into two seasons in the Wenatchee basin by the annual runoff which peaks in June (Figure 6). During high runoff periods, periphyton growth is interrupted by scouring of periphyton biomass and dilution with low-nutrient snow-melt runoff. By contrast, there was little seasonal pH variation at the Tumwater Canyon station (there were two high pH excursions in the entire record; April 1997 and November 1998).



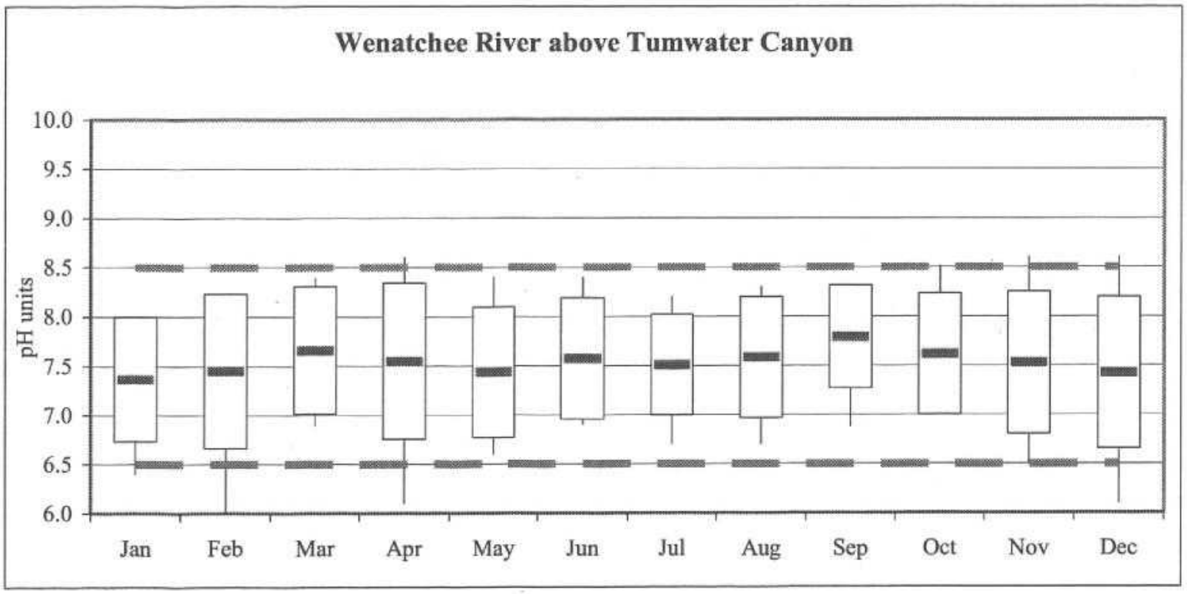


Figure 5. Box plot summary of monthly instantaneous pH measurements from Ecology ambient stations on the Wenatchee River at the mouth (45A070) and above Tumwater Canyon (45A110) from 1994 to 2004 (n = 14 to 16). Box plots depict monthly maximum, 90th percentile, mean, 10th percentile, and minimum. The 6.5 minimum and 8.5 maximum pH criteria are shown.

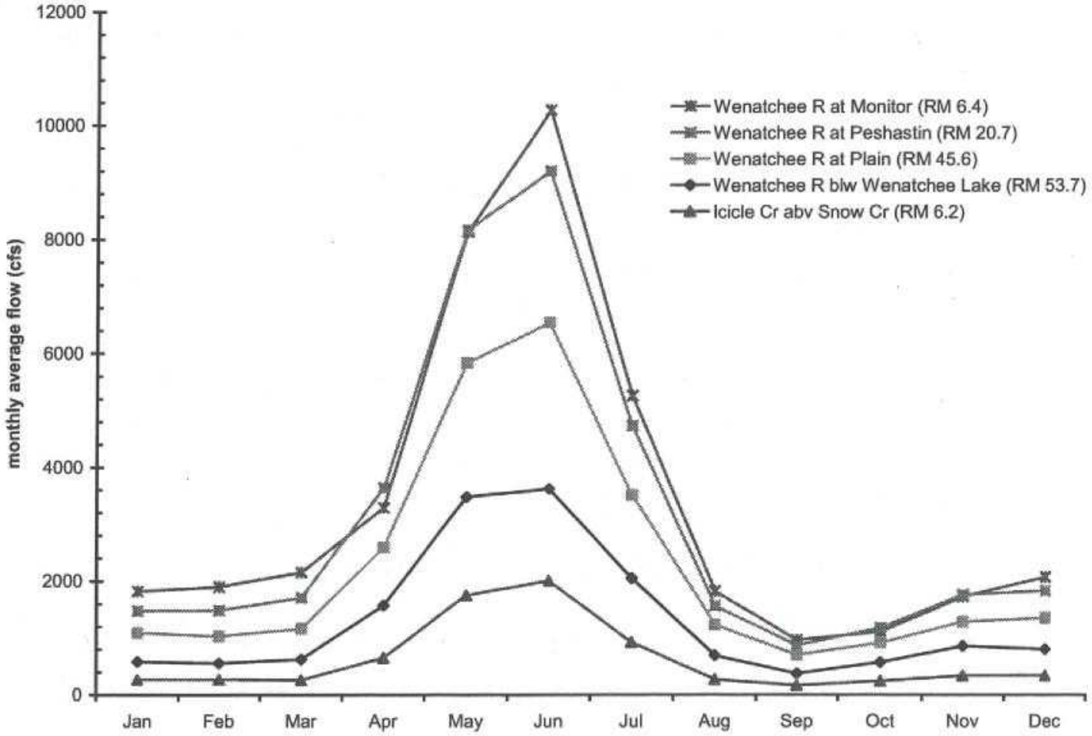


Figure 6. Monthly average flows at USGS gaging stations in the Wenatchee River watershed.

Figure 7 shows box plots of monthly instantaneous DO samples for the Wenatchee River at the mouth and above Tumwater Canyon taken by Ecology from 1993 to 2004. The instantaneous DO measurements did not necessarily capture the daily minimum because they were made during daylight hours when photosynthesis is increasing water column DO. Above Tumwater Canyon, low DO (including many readings below the Class AA criterion of 9.5 mg/L) occurred from mid-July to mid-September. July through September is the season of highest water temperatures and lowest flow in the Wenatchee River. By contrast, at the mouth, DO readings did not drop below the Class A water quality criterion of 8.0 mg/L; but again, measurements were made during daylight hours when daily DO was not at its minimum. The lowest DO measurements at the mouth also occurred from July through September.

Figure 8 shows box plots of monthly instantaneous DO deficits (departure from DO saturation concentrations) for the Wenatchee River at the mouth and above Tumwater Canyon from 1993 to 2004. Again, the measurements were made during daylight hours when photosynthesis contributed to over-saturated conditions. The DO deficits do not necessarily reflect the maximum DO departure, either, because the measurements were made at different times of the day. At the mouth, the greatest DO concentrations above saturation (mean DO deficit > 1.0 mg/L) occurred in March/April and August to October, concurrent with the highest periphyton growth periods in the lower Wenatchee River. By contrast, the Tumwater Canyon station monthly mean DO deficits were minimal, although there was more variability from October to December.

Ecology does not have long-term ambient monitoring stations on Icicle Creek; however, the Chelan County Conservation District monitored two sites in 1992-93. At the East Leavenworth Road bridge station, low DO and pH excursions from water quality criteria generally occurred in late summer (September-October). At the Bridge Creek station, DO values below the Class AA 9.5 mg/L criterion generally occurred between July and November.

All historical data indicate that the season of concern for pH and DO is during the periphyton growing season from March through October, when biomass and growth are greatest. This season is interrupted from May through July due to spring runoff. There were a few pH excursions extending into the winter months of November and December. These are most likely due to periphyton biomass accumulation through the summer and fall growing season; biomass control during the growing season will likely mitigate winter-time excursions.

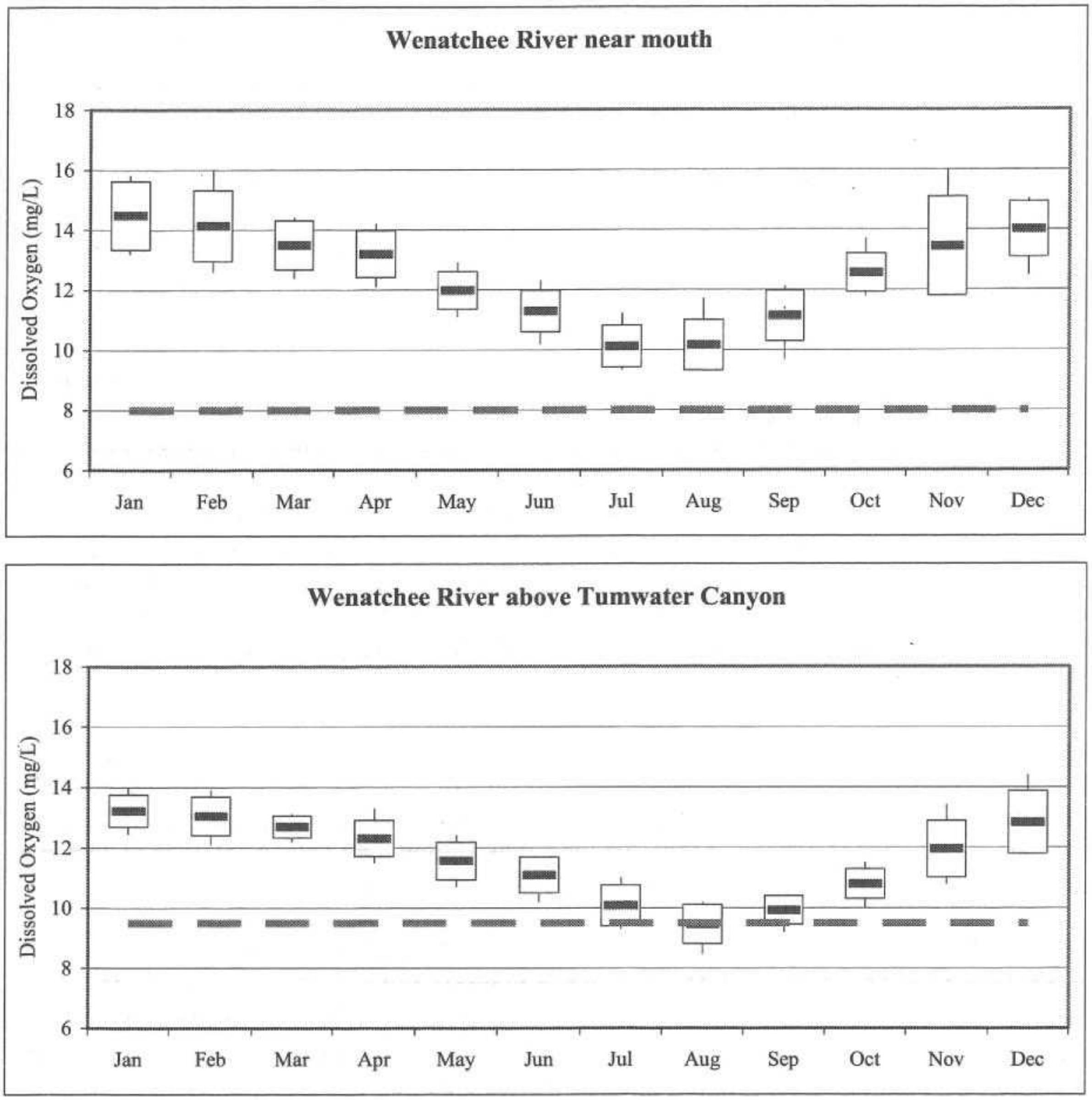
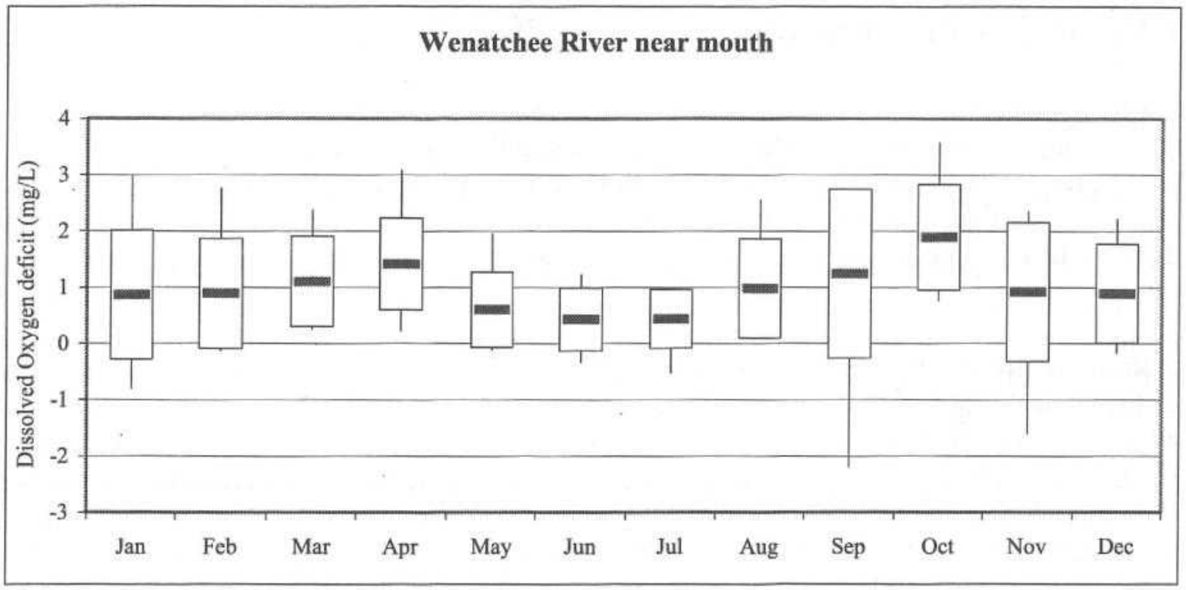


Figure 7. Box plot summary of monthly instantaneous dissolved oxygen measurements from Ecology ambient stations on the Wenatchee River at the mouth (45A070) and above Tumwater Canyon (45A110) from 1994 to 2004 (n = 14 to 16). The mouth is Class A water, and above Tumwater Canyon is Class AA water. Box plots depict monthly maximum, 90th percentile, mean, 10th percentile, and minimum. The Class A (8.0 mg/L) and Class AA (9.5 mg/L) dissolved oxygen criteria are shown for each respective station.



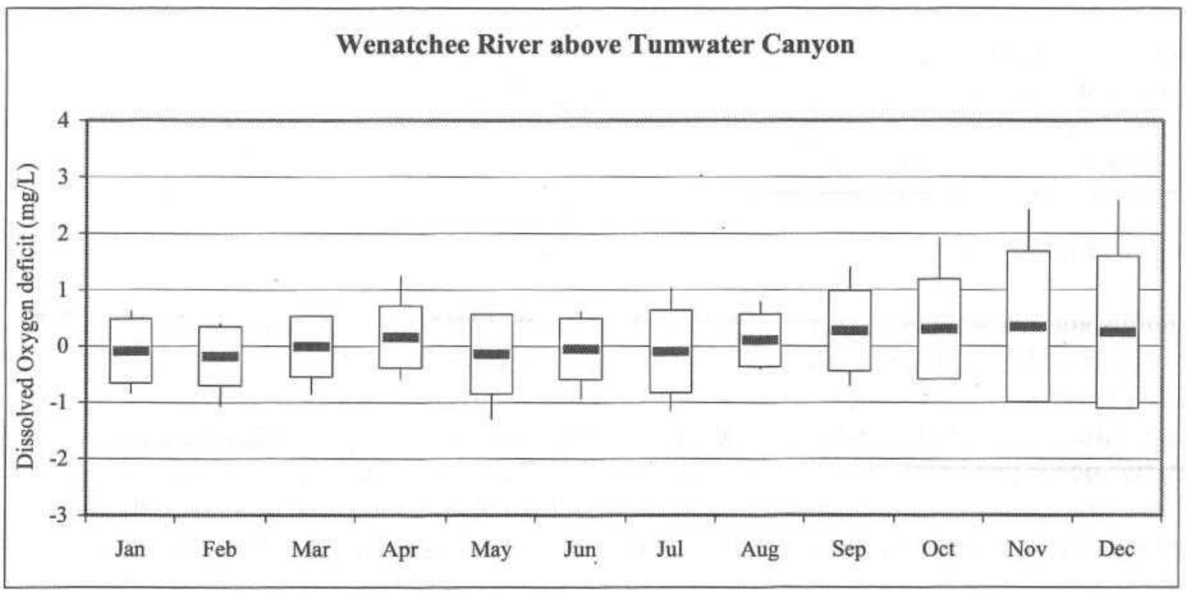


Figure 8. Box plot summary of monthly instantaneous dissolved oxygen deficit measurements, relative to saturation, from Ecology ambient stations on the Wenatchee River at the mouth (45A070) and above Tumwater Canyon (45A110) from 1994 to 2004 (n = 14 to 16). Box plots depict monthly maximum, 90^{th} percentile, mean, 10^{th} percentile, and minimum.

Wenatchee River and Icicle Creek 2002-03 Data Results

In accordance with the seasons of concern, Ecology conducted monthly synoptic surveys from July to October 2002 and one synoptic survey in April 2003 in the Wenatchee River and Icicle Creek. A synoptic survey is defined as data collection from many sampling sites over a short time interval. In addition to the synoptic surveys, core stations were sampled once a month from June 2002 to January 2003, concurrent with synoptic surveys when applicable, to develop time series data.

Flow conditions are an important consideration when conducting TMDL studies. Ecology defines the critical low-flow river condition for TMDL studies to be the 7-day-average low-flow with a reoccurrence interval of once every 10 years on the average (7Q10) (i.e., a 10^{th} percentile flow). The seasonal (July through October) 7Q10 for the Wenatchee River at Monitor is 344 cfs (based on the 1962 to 2003 USGS record at Monitor). The 2002 seasonal 7-day low-flow was 406 cfs (or approximately a 20^{th} percentile flow). This means that water quality standard exceedances observed in 2002 might be worse in a critical year with 7Q10 conditions.

The following is a brief review of the data results for these parameters, including a summary of observed water quality standard exceedances during 2002-03.

Dissolved Oxygen and pH

Class AA reaches

Continuous and instantaneous (grab sample) data show that DO concentrations in the Wenatchee River and Icicle Creek were sometimes below the DO criterion of 9.5 mg/L in their respective Class AA water segments. The Class AA waters begin and continue upstream from the first junction with the Wenatchee National Forest boundary. The Wenatchee National Forest boundaries occur just upstream of Leavenworth within Tumwater Canyon on the Wenatchee River and just upstream of the Leavenworth National Fish Hatchery on Icicle Creek. Private land ownership is interspersed with public ownership above these Class AA boundaries.

At least nine out of 25 continuous data-logger, time-series data sets from eight Class AA reaches of the Wenatchee River, Icicle Creek, or their tributaries showed DO concentrations less than the 9.5 mg/L criterion during at least part of the day. Most DO time-series showing excursions were from the late August survey when water temperatures were warm (>18.0 C) and diel water temperature change was approximately 3-4 °C. DO excursions below 9.5 mg/L also occurred during the July and September surveys.

Figure 9 is an example of the data-logger continuous data from one Class AA site. The diel change in DO concentration in this Class AA reach was mostly due to the diel change in water temperature which, in combination with the higher land elevations, affected the DO solubility in water (i.e., temperature is the main factor causing the DO excursions). When water temperatures dropped, the DO solubility increased and DO diffused into the water through reaeration. When the water temperature rose, the DO solubility decreased and DO diffused to the atmosphere. The lag (i.e., phase shift) in the observed DO data curve peak from the DO saturation curve peak is due to a delay in reaeration and is an indirect measurement of the reaeration rate for the conditions at that particular site and time.

Cristea and Pelletier (2005) used effective shade as a surrogate for thermal load in developing a temperature TMDL for the Wenatchee River watershed. They found that during critical conditions the site-potential effective shade in some places was not sufficient to meet the numeric water temperature criteria, implying that, at times, natural conditions may exceed the numeric temperature criteria (in which case the natural condition becomes the criterion). It should be noted that even when the water temperatures met the Class AA criterion of 16° C, DO concentrations of less than 9.5 mg/L were observed (Figure 9), because the DO saturation was below 9.5 mg/L. In these Class AA reaches, natural DO concentrations will be less than 9.5 mg/L during the summer months due to the high land elevations and high water temperatures.

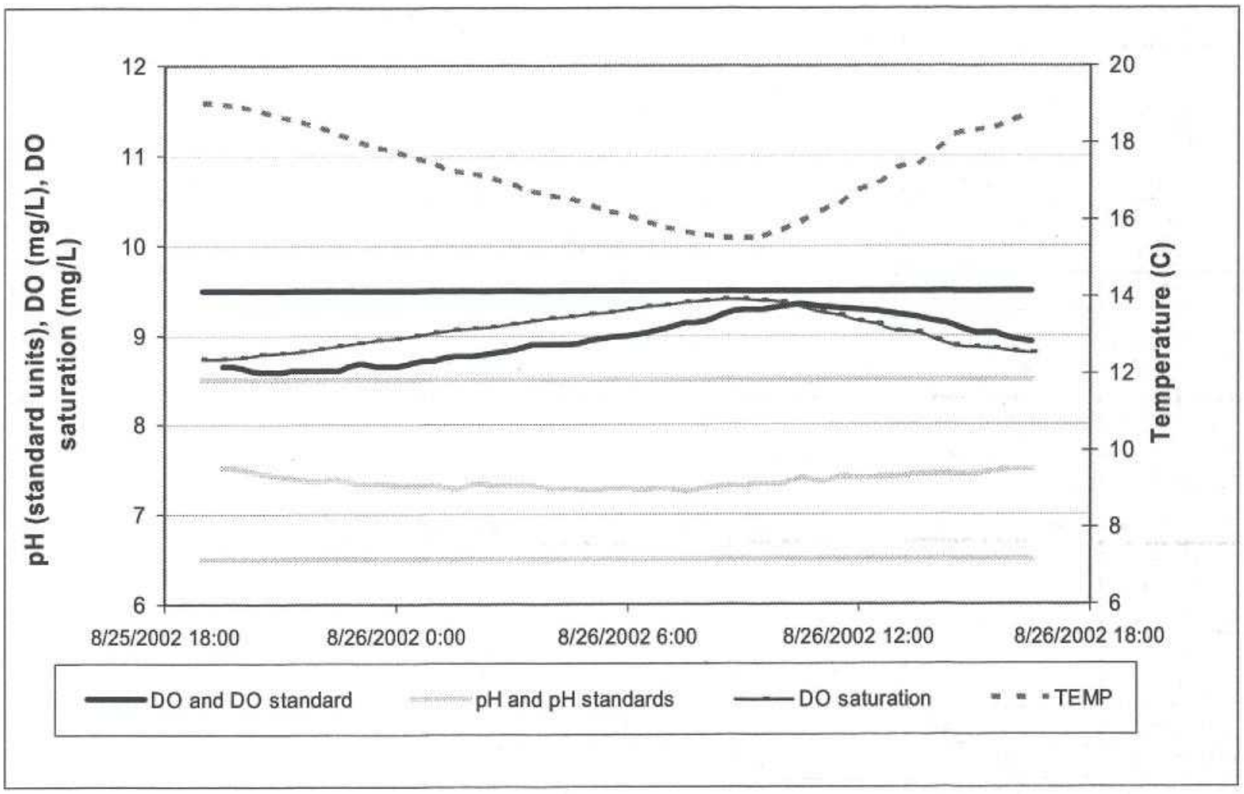


Figure 9. Continuous dissolved oxygen, pH, and temperature data from the Wenatchee River at the Tumwater Canyon Highway 2 bridge (station 45WR35.4) for August 25-26, 2002.

In addition to the data-logger profiles, Table 16 presents the 22 grab sample (instantaneous) DO readings that show values below the Class AA numeric criterion in the Wenatchee River, Icicle Creek, or immediate tributaries to the Class AA reaches. Sites 45BC00.1 and 45WDB included irrigation management return flow from the Chiwawa Irrigation District. Two sites, both outlets of the Wenatchee River headwater lakes (Lake Wenatchee and Fish Lake), each had one DO reading less than 8.0 mg/L. With the exception of these two lake outlet readings, the criterion excursions are most likely from high water temperatures causing low DO solubility as seen in the data-logger, time-series data sets. The reason for the two very low DO readings from the lake outlets is not understood at this time.

All pH values from instantaneous measurements and data-loggers fell within the water quality standards range of 6.5 to 8.5 pH units in Class AA river reaches.

Table 16. Instantaneous (grab sample) dissolved oxygen excursions below the water quality criterion of 9.5 mg/L in the Class AA reaches of the Wenatchee River, Icicle Creek, and their tributaries ("J" values are qualified as estimates).

Station	Date	Time	DO (mg/L)	Qualifier
45BC00.1	7/22/2002	12:50:00	9.2	
45BC00.1	8/26/2002	11:37:00	9.4	
45FL00.3	6/25/2002	11:05:00	7.62	
45FL00.3	7/22/2002	10:55:00	5.62	
45IC15.7	7/23/2002	10:30:00	9.48	
45JC00.1	9/24/2002	9:45:00	9.46	J
45LR01.2	8/26/2002	9:00:00	9.02	
45SC00.1	7/23/2002	12:35:00	8.67	
45WDA	8/26/2002	12:20:00	9.44	
45WDB	8/26/2002	12:40:00	9.24	
45WH01.9	8/26/2002	9:30:00	9.44	
45WR30.7	9/23/2002	11:45:00	8.75	J
45WR30.7	10/22/2002	12:00:00	9.35	J
45WR35.4	8/26/2002	10:55:00	9.27	
45WR41.8	7/22/2002	13:30:00	9.45	
45WR41.8	8/26/2002	12:55:00	9.31	
45WR46.2	8/26/2002	12:05:00	9.25	
45WR54.0	12/3/2002	11:05:00	7.01	J
45WR54.0	9/10/2002	13:32:00	9.36	J
45WR54.0	8/6/2002	10:30:00	9.18	
45WR54.0	8/26/2002	9:55:00	9.05	J
45WR54.0	10/21/2002	11:15:00	9.41	

Class A reaches

In the Class A reaches of the Wenatchee River and Icicle Creek, DO and pH water quality criteria excursions were observed in the continuous and grab sample data. In these reaches, the diel changes in the continuous DO and pH data were primarily due to photosynthesis and respiration of periphyton (attached algae). Periphyton respiration and photosynthesis can cause large diel fluctuation in DO and pH (Wetzel, 1983; Welch, 1992). Photosynthesis dominates during daylight hours and respiration dominates at night. DO is generated during photosynthesis, producing maximum DO concentrations in the afternoon. Respiration by periphyton and bacteria consumes DO, causing minimum DO concentrations usually in the early morning just before sunrise.

Photosynthesis and respiration also affect pH throughout the day. Periphyton consume dissolved inorganic carbon during photosynthesis, leading to maximum pH values in the afternoon. Overnight respiration increases dissolved inorganic carbon causing minimum early morning pH values. Figure 10 presents a data-logger profile from station 45WR01.0, Wenatchee River above the mouth, showing diel changes in DO and pH on August 28-30, 2002.

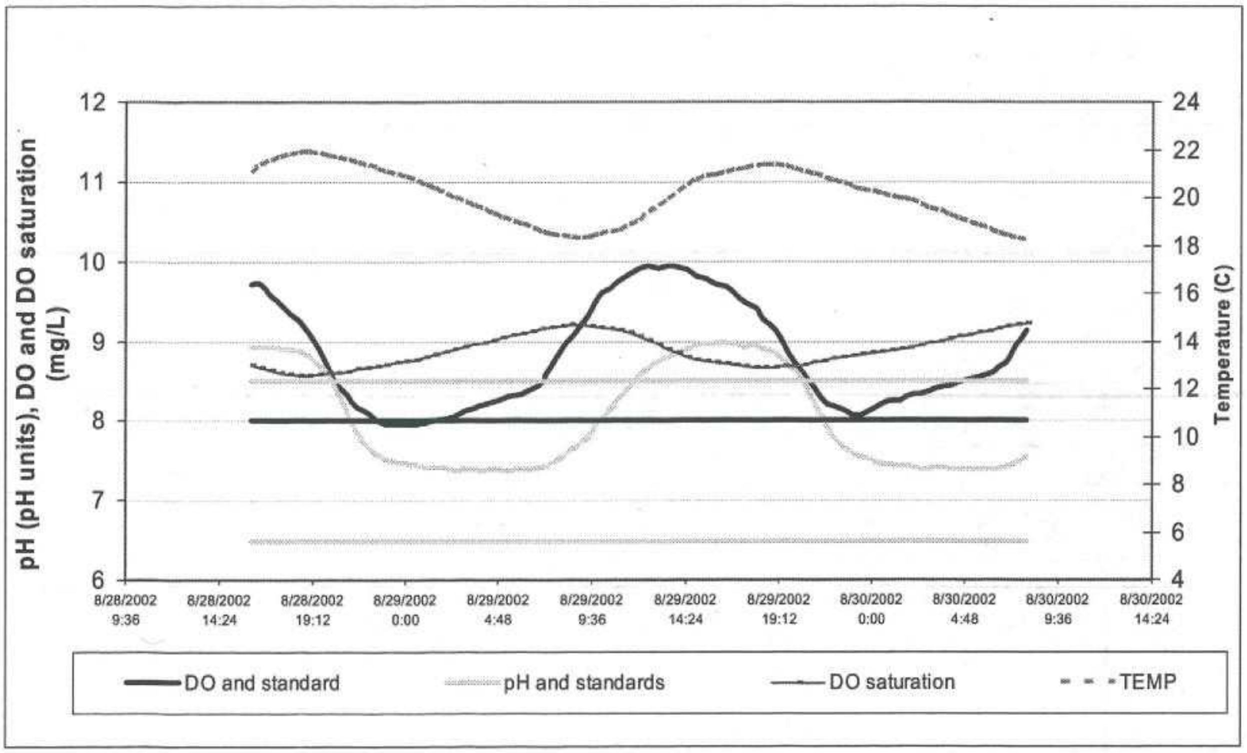


Figure 10. Continuous dissolved oxygen, pH, and temperature data from one mile upstream from the mouth of the Wenatchee River (station 45WR01.0) for August 28-30, 2002.

Table 17 contains a summary of the stations in Class A waters with observed DO and pH water quality criteria excursions based on the data-logger, time-series data sets (blank boxes indicate that no time-series was taken). On Icicle Creek, only the mouth (45IC00.1) showed pH exceedances. On the Wenatchee River, all the DO and pH excursions occurred at stations between the Peshastin station (RM 21.0) and the mouth. Similarly, all instantaneous (grab sample) pH readings higher than the pH criterion occurred in the same lower Wenatchee River reach (Table 18).

Table 17. Summary of Class A stations showing dissolved oxygen and/or pH water quality criteria excursions in data-logger, time-series profiles. "Yes" indicates an excursion, "No" indicates no excursion, and blanks indicate that a time-series was not taken at the station for that month.

Station	July-02		August-02		September-02		October-02		April-03	
	DO	pH	DO	pH	DO	pH	DO	pH	DO	pH
45WR21.0	No	No	No	No	No	Yes			No	No
45WR17.2	Yes	No	No	Yes	No	Yes				
45WR14.1	No	No	No	Yes						
45WR10.8			No	Yes	No	Yes				
45WR06.5			Yes	Yes	No	Yes			No	Yes
45WR01.0			Yes	Yes	No	Yes	No	Yes	No	Yes
45IC00.1	No	No	No	Yes	No	Yes	No	No	No	No

Table 18. Instantaneous pH and dissolved oxygen water quality criteria excursions from 2002-03 sampling in the Class A waters of the Wenatchee River basin.

Station	Date	Time	pH		Station	Date	Time	DO (mg/L)	
45HR00.1	10/9/2002	15:05:00	10.04		45BR00.1	10/9/2002	14:30:00	5.03	J
45IC02.3	9/24/2002	13:20:00	8.51		45BR00.1	8/28/2002	14:20:00	7.37	J
45WR01.0	4/9/2003	11:55:00	8.61		45BR00.1	10/22/2002	12:30:00	7.62	
45WR02.8	9/25/2002	12:30:00	8.55		45BR00.1	7/24/2002	12:40:00	7.15	
45WR06.5	9/25/2002	12:55:00	8.79		45CD00.1	7/22/2002	12:25:00	7.8	
45WR06.5	10/9/2002	14:50:00	9.13		45CR00.1	7/24/2002	8:25:00	7.6	
45WR06.5	11/13/2002	14:55:00	9.14		45MC00.2	7/24/2002	12:20:00	7.68	
45WR06.5	4/9/2003	10:55:00	8.56						
45WR06.5	8/28/2002	12:45:00	8.52						
45WR06.5	12/3/2002	14:35:00	8.67						
45WR06.5	1/7/2002	14:30:00	8.66	J					
45WR10.8	4/9/2003	12:50:00	8.56						
45WR10.8	10/22/2002	13:15:00	8.71						
45WR14.1	10/9/2002	14:15:00	8.62						
45WR14.1	11/13/2002	13:55:00	8.62						
45WR17.2	8/28/2002	12:25:00	8.71						
45WR17.2	10/22/2002	15:05:00	8.75						
45WR21.0	10/22/2002	14:20:00	8.56						

DO water quality criteria excursions occurred only in the July and August surveys, a time of elevated water temperatures (i.e., less DO solubility). Otherwise sufficient reaeration appeared to compensate for plant respiration. pH exceedances occurred in every survey from August to January, and in April, indicating that the onset of excessive periphyton productivity (i.e., enough to cause pH exceedances) occurred in August and continued through the winter despite very low water temperatures in the winter (growth rates for periphyton are temperature-dependent).

There appears to be a low DO condition in a side channel of the mouth of the Wenatchee River at the confluence with the Columbia River. A left-bank side channel (Figure 11) formed by an island at RM 0.5 is water-quality impaired.

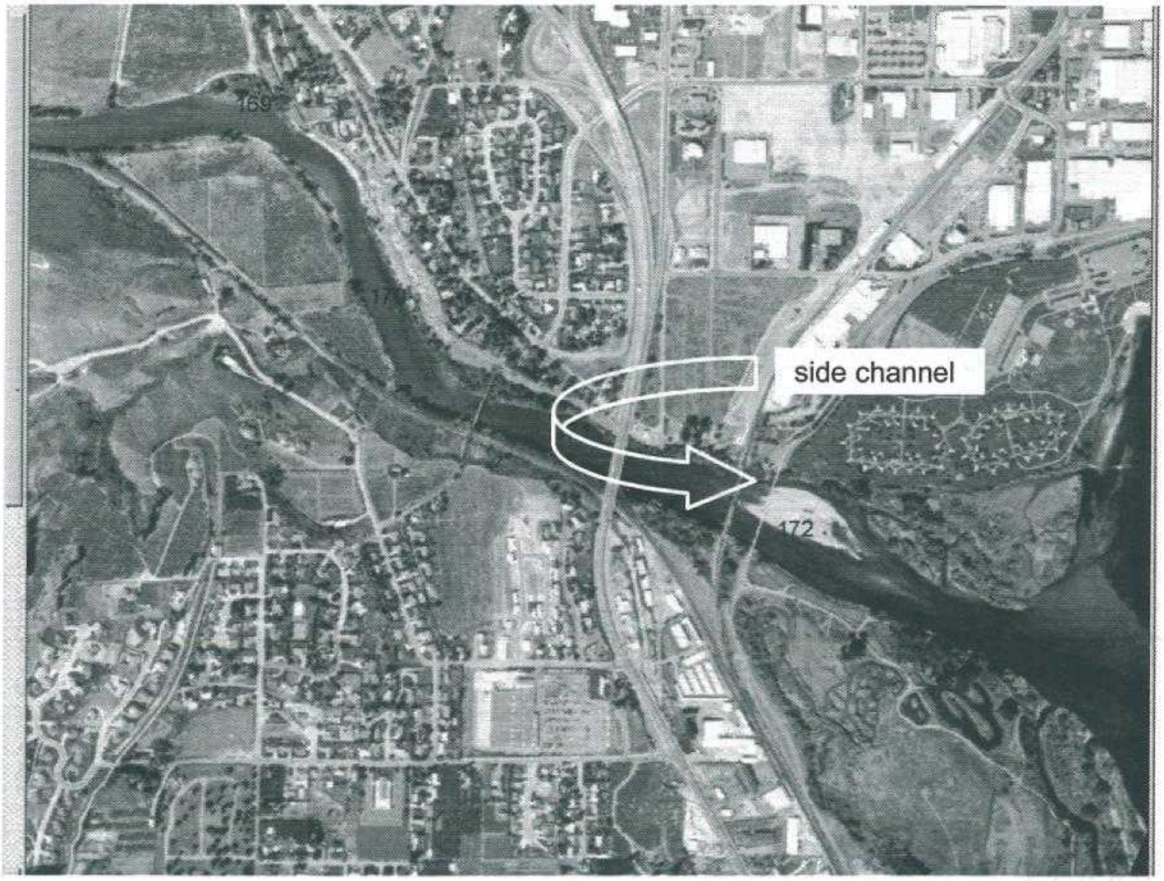


Figure 11. Map of mouth of the Wenatchee River showing the island at RM 0.5 with side channel on the left bank and main channel on the right bank.

A data-logger deployment on August 28, 2002 in the side channel showed DO levels dropping to below 6 mg/L (Figure 12). Oscillations (upstream and downstream movement of water) were visible on this date and are indicated in the DO profile as up and down spikes. Complex hydrodynamics within this side channel create a back flow of water depending on changes in the level of the Columbia River (perhaps from daily adjustment at Rock Island Dam for power generation or from upstream surges). The data show a dominating diel effect due to algal photosynthesis and respiration, but the low DO may be exacerbated by oxidation of organic matter interned in this side channel, and/or reduced reaeration due to the rising water of the Columbia River. The deleterious DO effects seen in 2002 could be worse during 7Q10 critical flow conditions.

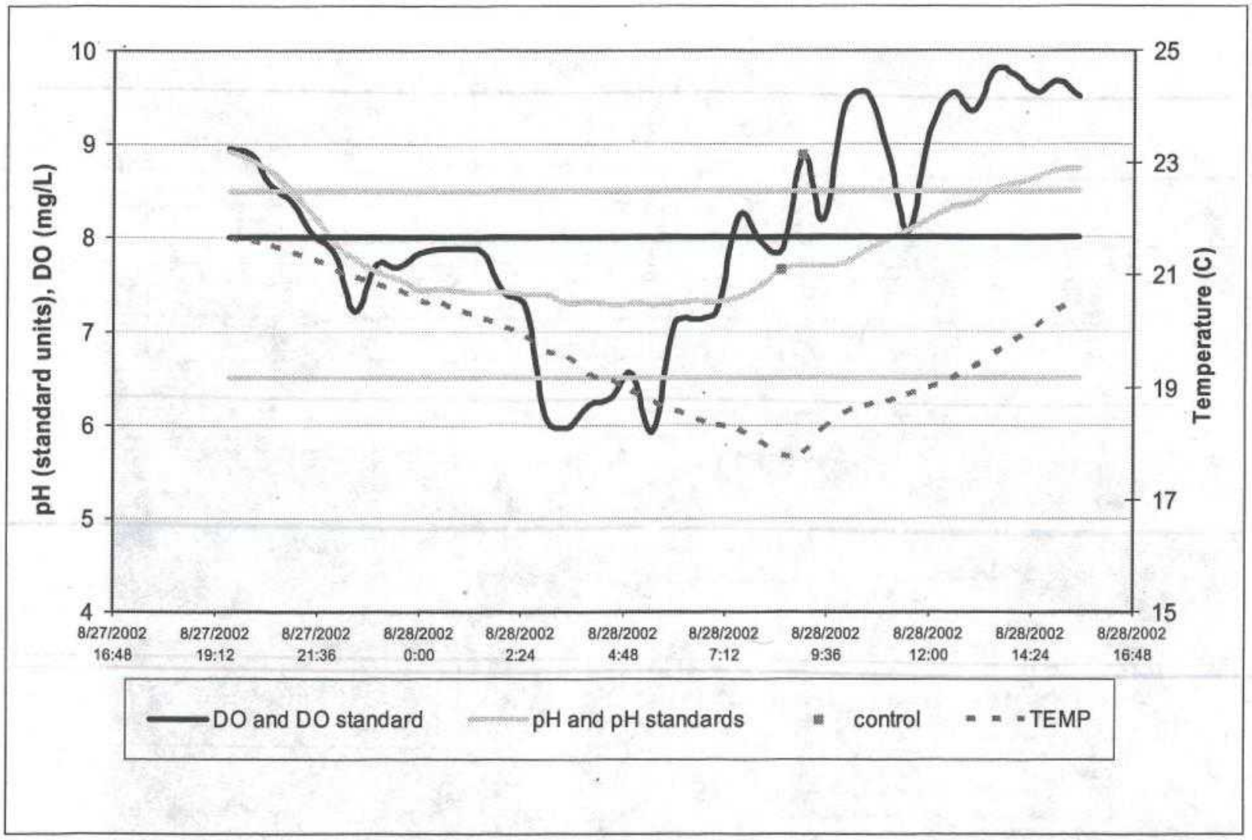


Figure 12. Diel data collected with a data logger at the mouth of the Wenatchee River (station 45WR00.5) on August 27-28, 2002.

This condition in the side channel does not appear to be representative of the hydrodynamics or water quality of the main channel (i.e., on the right bank) where flow appears to be continuous. A more detailed low-flow study of the main channel was cancelled in 2004 due to rain and high flow; however, a two-week data-logger deployment in the main channel during October 2004 showed large diel pH and DO swings (e.g., ≈ 2 pH units and 3 mg/L, respectively) and daily pH exceedances above the 8.5 criterion even though flows were high (e.g., ≈ 2000 cfs) and water temperatures cool (Figure 13). How DO and pH are influenced in the main channel by the pooling effect during critical condition is unknown at present and is beyond the scope of this TMDL study without further data collection.

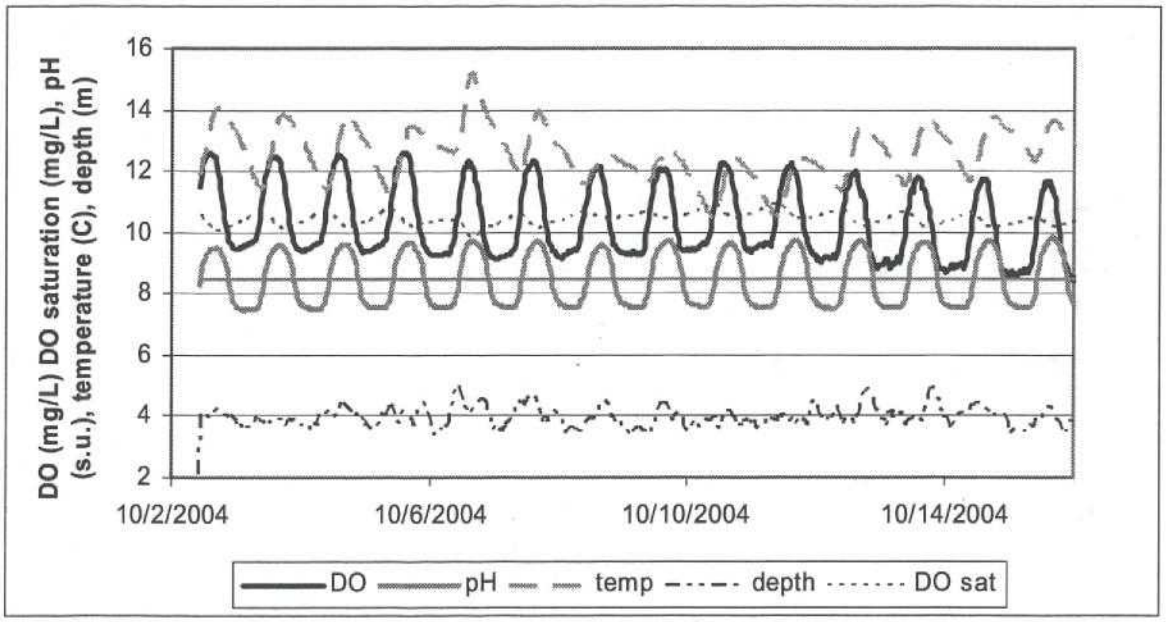


Figure 13. Diel data collected with a data logger in the main channel of the mouth of the Wenatchee River (River Mile 0.5) from October 2-16, 2004. The upper pH criterion of 8.5 is delineated.

Nutrients (Nitrogen and Phosphorus)

Nutrients (nitrogen and phosphorus) are necessary for growth of periphyton, and phosphorus is often the most limiting nutrient for algal growth in natural freshwater (Wetzel, 1983). This is particularly true if the dissolved inorganic nitrogen to orthophosphate ratio (N:P ratio) is greater than 7 (Reynolds, 1984). Figure 14 presents the N:P ratios (dissolved inorganic fractions) for the Wenatchee River by monthly survey. In general, the N:P ratio is above 7 in the river at all times, indicating phosphorus limitation. The exception was above RM 17 during the growing season (July through October) when the N:P ratios were below 7 and nitrogen may have been limiting. However, the nitrate and/or orthophosphate concentrations above RM 17 during the growing season were at or below reporting limits (10 ug/L and 3 ug/L, respectively) so the true N:P ratios are unknown. In general, there was limited periphyton biomass in these upper reaches due to the general lack of both nitrogen and phosphorus.

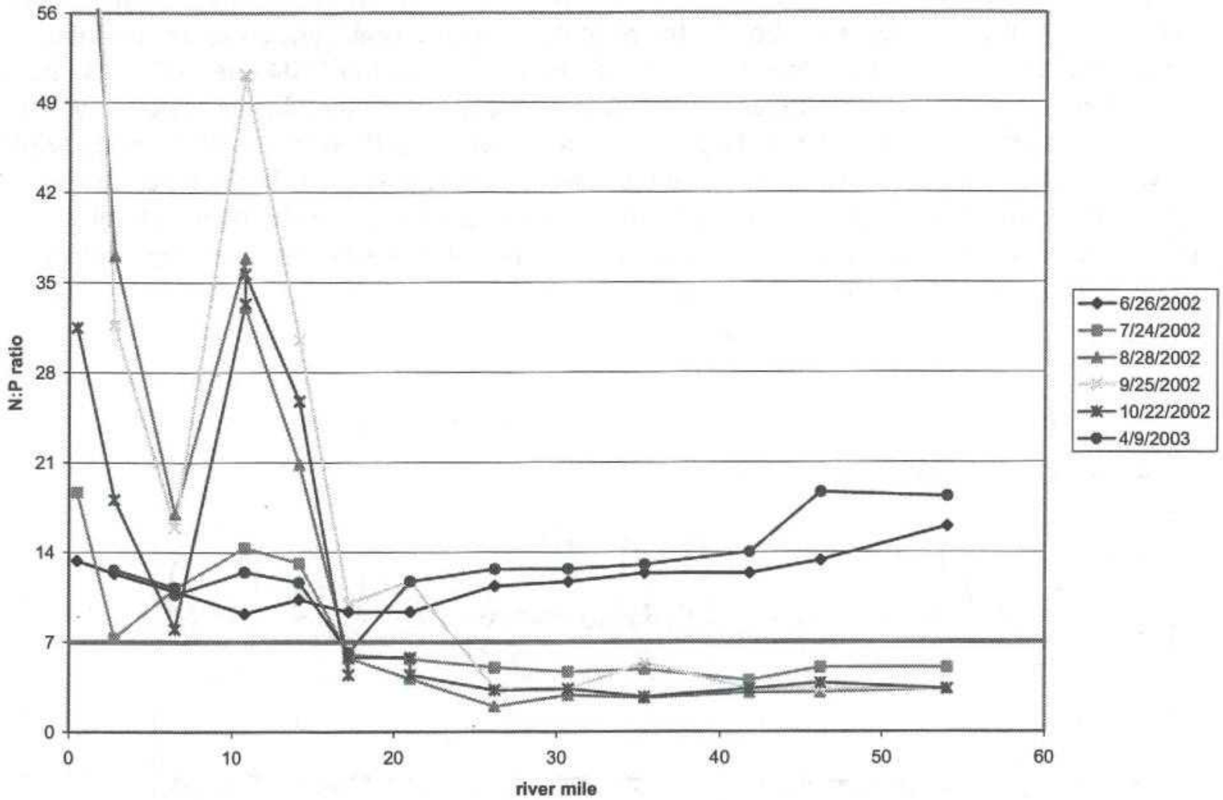


Figure 14. Nitrogen:phosphorus ratios (dissolved inorganic nitrogen to orthophosphate ratio) for the Wenatchee River by river mile for each monthly survey.

Figure 15 shows the orthophosphate concentrations for the monthly surveys by river mile, from Lake Wenatchee (RM 54.0) to just above the mouth (RM 0.5). The graph shows that orthophosphate concentrations remain low (less than 4 ug/L) from Lake Wenatchee to below the city of Leavenworth, and then increase moving downstream from Leavenworth, particularly in the months of September and October when flows were lowest in the river (i.e., when there is less dilution of diffuse inflows). There is an increase in bio-available phosphorus in the lower reach of the Wenatchee River (i.e., below Leavenworth) that fuels an increase in periphyton biomass and growth resulting in the observed pH and DO exceedances found in the lower Wenatchee River reaches. The orthophosphate concentration levels are relatively low (e.g., <20 ug/L orthophosphate) compared to other streams in Washington State; however, the water column nutrient concentrations would be higher without periphyton uptake. In essence, the resulting water column orthophosphate concentrations are net concentrations reflecting a steady state condition of loading and loss (e.g., uptake, settling) at each sampling location.

Figure 16 shows the nitrate-nitrite concentrations for the monthly surveys by river mile, from Lake Wenatchee (RM 54.0) to just above the mouth (RM 0.5). Similar to orthophosphate, the data showed increasing concentrations in the lower river during low-flow conditions

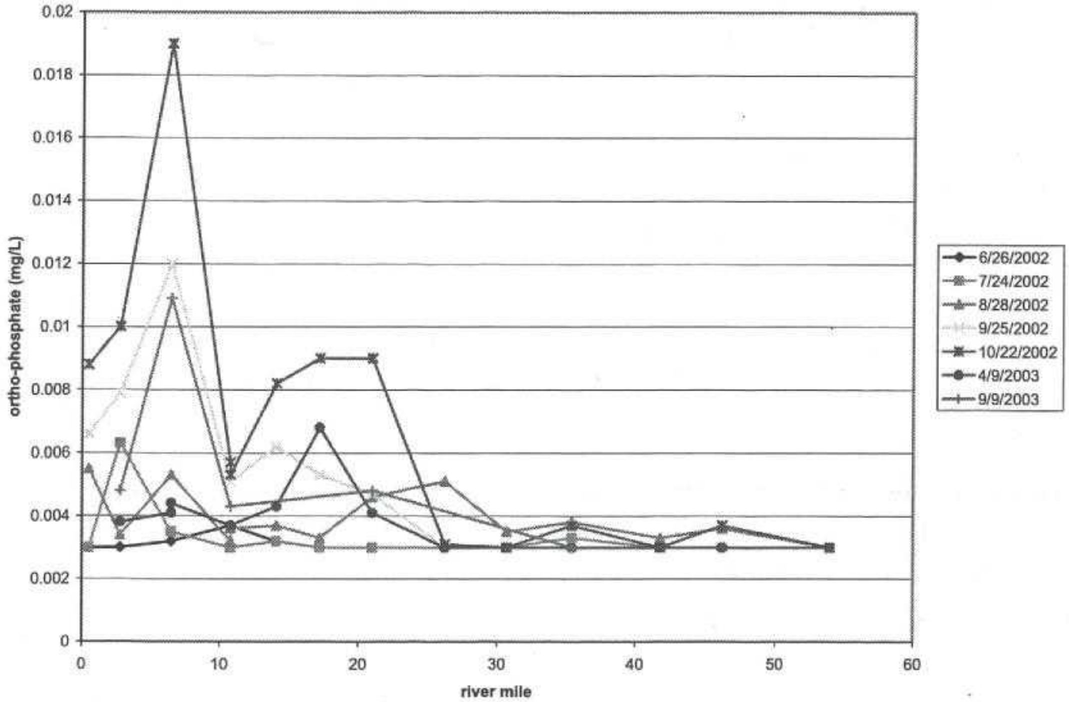


Figure 15. Orthophosphate concentrations for the monthly surveys by river mile, from Lake Wenatchee (RM 54.0) to just above the mouth (RM 0.5). Reporting limit for orthophosphate is 0.003 mg/L.

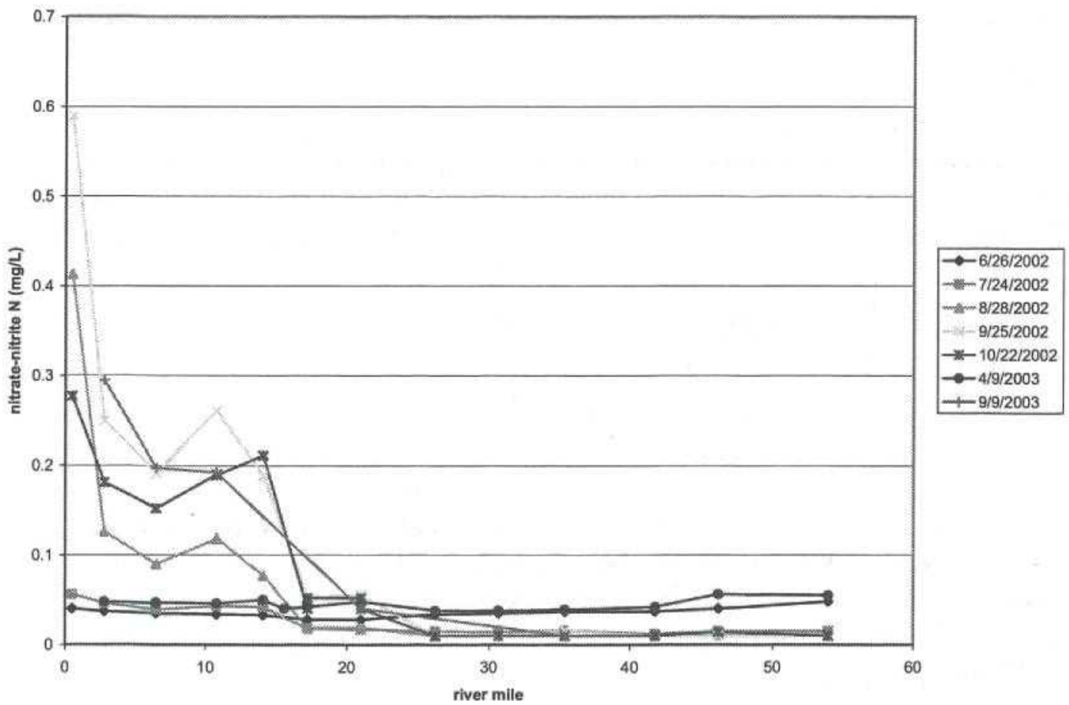


Figure 16. Nitrate-nitrite concentrations for the monthly surveys by river mile, from Lake Wenatchee (RM 54.0) to just above the mouth (RM 0.5).

Sources of Phosphorus and Biochemical Oxygen Demand (BOD)

Five facilities have individual National Pollutant Discharge Elimination System (NPDES) permits for discharging to either Icicle Creek or the Wenatchee River. Effluent from the following facilities was sampled for this TMDL study:

Icicle Creek

- City of Leavenworth Water Treatment Plant (WTP)

Wenatchee River

- Lake Wenatchee Publicly-Owned Treatment Works (POTW) (influent station name: LAKEWNI; effluent station name: LAKEWNE)
- City of Leavenworth POTW (station name: LEAVWWTP)
- City of Peshastin POTW (station name: PESHTN)
- City of Cashmere POTW (station name: CASHMR)

Appendix A and B contain a summary of the permit limits for these facilities and a synopsis of field notes taken during the sampling surveys.

The following fruit processors have a general permit to discharge non-contact cooling water to the Wenatchee River. These fruit processors were also sampled for this TMDL study:

- Bardin Farms Corporation in Monitor
- Blue Star Growers, Inc. in Cashmere
- Blue Bird, Inc. in Peshastin

The following fish hatcheries have an NPDES General Upland Fin-Fish Hatching and Rearing Discharge Permit for Icicle Creek, Wenatchee River, and/or the Chiwawa River:

- Leavenworth National Fish Hatchery [station names: 45LNFHA (abatement pond); 45LNFHD (return Ditch); 45LNFHO (main outlet); and 45LNFHS (below spillway)]
- Chiwawa Ponds Hatchery (station name: 45CW00.5)
- Dryden Ponds Hatchery (station name: 45WR15.6)

Irrigation water purveyors have recently been required by law to obtain an NPDES permit for discharge back to natural waterways if applying aquatic herbicides in their water canals or ditches. Aquatic weeds and periphyton within the irrigation canals as well as nonpoint sources to irrigation canals may contribute BOD and phosphorus loads to the Wenatchee system. The following irrigation water districts or purveyors divert and discharge to waters within the Wenatchee River basin:

- Icicle and Peshastin Creek Irrigation District
- Cascade Orchards Irrigation District
- Chiwawa Irrigation District

- Wenatchee Reclamation District
- Jones Shotwell Irrigation District
- Gunn Ditch Irrigation District

The following tributaries discharge to the Wenatchee River during the summer low-flow period:

- Nason Creek. The Stevens Pass Sewer District has a small Class IV Advanced Wastewater Treatment plant (tertiary treatment using a membrane bioreactor ultra-filtration process) that services the ski resort area and has an NPDES permit to discharge to Nason Creek.
- Chiwawa River. This river drains primarily Forest Service lands, although a community of private residences with on-site septic systems is established near the mouth of the river.
- Chiwaukum Creek. This creek drains primarily Forest Service lands, although a wastewater lagoon drains to groundwater near the mouth.
- Icicle Creek. This creek drains primarily Forest Service land but has multiple potential point and nonpoint source impacts from fish aquaculture, agriculture, and rural/urban sources.
- Chumstick Creek. This creek drains primarily Forest Service lands but has multiple potential nonpoint source impacts from both agricultural and rural/urban sources.
- Peshastin Creek. This creek drains primarily Forest Service lands, although Hwy 97 runs through the watershed.
- Mission Creek. This creek drains primarily Forest Service lands but has multiple potential nonpoint source impacts from both agricultural and urban sources.

Groundwater discharging to the Wenatchee River, Icicle Creek, and their tributaries also affects DO levels and nutrient concentrations. Groundwater discharges to the river or creeks in some reaches, and is recharged in other reaches. In the Wenatchee basin, background groundwater flow and BOD/nutrient concentrations may be elevated due to upland practices such as orchard irrigation and wastewater discharge to groundwater from on-site septic systems.

In addition, nonpoint sources along the length of the river may be contributing BOD and nutrients. There may be high-concentration, nonpoint source areas associated with large community on-site septic systems, a high density of individual on-site septic systems, or failing public wastewater collection or treatment systems. Most notable examples of such possible sources are the City of Dryden POTW that discharges wastewater to a large community drainfield alongside the Wenatchee River (fruit processors also land apply process water here), and the City of Cashmere POTW sewage lagoons which have been confirmed to be leaking alongside the Wenatchee River.

Other than the tributary, groundwater, and nonpoint loads described above, other nonpoint runoff sources along the mainstem of the river are probably relatively insignificant for this project because stormwater and combined sewer overflow discharges to the river do not occur during the period of concern. The contributions of BOD and nutrients from small discharges to the tributaries of the Wenatchee River and Icicle Creek were included as part of the tributary loading to the river, and not assessed as "discrete" loads for this study.

Water Quality Modeling

Water quality (periphyton production, pH, dissolved oxygen, and nutrients) was simulated in the Wenatchee River and Icicle Creek using the QUAL2K numerical model. Ultimately, since phosphorus is the limiting nutrient for the production of periphyton, the model was used to develop assimilative load capacities for phosphorus. Phosphorus controls periphyton growth which in turn controls excessive pH and dissolved oxygen diel swings. Eventually, the model will be used as a tool for developing a phosphorus allocation strategy to bring pH and dissolved oxygen into compliance with water quality standards in the Wenatchee basin.

There are several important concepts in modeling periphyton productivity in running waters. First, only one nutrient can limit algal growth at a time. The limiting nutrient will be the nutrient that is in least supply relative to its demand. The QUAL2K model uses carbon-to-nitrogen-to-phosphorus stoichiometric ratios of 40:7:1 (expressed as percentages of biomass dry weight). These ratios define the relative demand of each nutrient for algal growth. Secondly, in rivers, it is important to limit the growth rate in order to control the algal biomass yield. The growth rate is only limited by the concentration of the most limiting nutrient (i.e., the supply rate of the limiting nutrient) because rivers transport a continual downstream supply of nutrients at steady-state conditions. Finally, it is appropriate to use the dissolved-fraction concentration of the limiting nutrient (i.e., dissolved inorganic-phosphorus) as the basis for modeling periphyton growth because the nutrient has to be in a readily available form for biological uptake and growth to occur during steady-state solute transport (Welch and Jacoby, 2004).

QUAL2K Model Structure and Approach

QUAL2K is a one-dimensional, steady-state numerical model capable of simulating a variety of conservative and non-conservative water quality parameters (Chapra and Pelletier, 2003). QUAL2K is supported by EPA, and the model and documentation is available at the following EPA website: www.epa.gov/ATHENS/wwqtsc/html/qual2k.html. The State of Washington also supports a version of QUAL2K which has enhanced features and can be downloaded at www.ecy.wa.gov/programs/eap/models/index.html. QUAL2K assumes steady-state flow and hydraulics; however, the heat budget and temperature are simulated on a daily time scale. Diel variations in all water quality variables are simulated as well.

QUAL2K was calibrated to model the Wenatchee River between RM 52.4 (Lake Wenatchee outlet) and RM 1.0. The model concluded at RM 1.0 because of inadequate field data at the mouth to calibrate the model to potential backwater conditions. QUAL2K was also calibrated to model Icicle Creek from above Jack Creek to the mouth. The following state variables were used to simulate steady-state water quality conditions: water temperature, conductivity, chloride, total dissolved solids, dissolved oxygen, carbonaceous biochemical oxygen demand (CBOD), alkalinity, total inorganic carbon, pH, periphyton biomass, nitrogen (N) in the forms of organic-N, ammonia-N, and nitrate-N, and phosphorus (P) in the forms of organic-P and dissolved inorganic-P (orthophosphate). The study portion of the Wenatchee River was divided into 84 one-kilometer reaches for QUAL2K modeling, and the study portion of Icicle Creek was divided into 60 one-half kilometer reaches. Tables of reaches are presented in Appendix D. Each reach was assumed to have uniform steady-state flow conditions.

Temperature was simulated for the four synoptic surveys (July, August, and September 2002, and April 2003). To better understand seasonal hydrology and diffuse source inputs in the Wenatchee River, QUAL2K simulations were set up for the months of July to October and calibrated for flow and conservative tracers.

For water quality calibration, two Wenatchee River and two Icicle Creek simulations were calibrated using data collected during the August and September 2002 field synoptic surveys. The August and September synoptic survey data provided unique critical-condition data sets (i.e., low-flow season). Only fixed model inputs (i.e., observed or measured flow, meteorology, and water quality data inputs) were changed between the two model runs. After an optimum calibration was achieved, the model was used to simulate critical-condition loading and 7Q10 flow conditions.

QUAL2K Model Calibration

Fixed Model Inputs

Hydrology

QUAL2K uses flow-exponent power equations to functionally represent the hydraulic routing of the river. The flow-exponent equations relating velocity (V in m/sec), depth (D in m), and width (W in m) with flow (Q in cms) are written as follows (McCutcheon, 1989):

$$V = a\,Q^b \qquad D = c\,Q^d \qquad W = eQ^f \qquad \text{(equation 1)}$$

Flow and channel width relationships were developed by digitizing segment channel widths from aerial photos representing 2-3 different flows. Channel cross-section velocity data at USGS gage stations were used to develop flow and velocity relationships. The flow-exponent equations for lower Icicle Creek from RM 4.1 to the mouth were developed from an existing Icicle Creek HEC-RAS model (ENSR Consulting and Engineering, 2000).

Flow balances were developed for each of the synoptic surveys using measured or gaged headwater, tributary, and point source inflows. Residual inflows and outflows were calculated from differences in the flow mass balance between USGS gaging stations. Residual flows were entered into the QUAL2K model as distributed diffuse inflows or outflows. Figure 17 presents the QUAL2K flow balances for the four synoptic surveys on the Wenatchee River, and Figure 18 presents the QUAL2K flow balances for the August and September synoptic surveys on Icicle Creek. Withdrawals in Icicle Creek nearly completely dewatered a portion of the channel in September 2002; the flow in Icicle Creek was restored downstream of the Leavenworth National Fish Hatchery by the hatchery's discharge back to the creek.

Water velocity and hydraulic routing on the Wenatchee River was confirmed with a time-of-travel dye study conducted September 9-12, 2002 from Lake Wenatchee (RM 54.0) to the Sleepy Hollow bridge at RM 2.8. Comparison of the QUAL2K model fit to travel time data is shown in Figure 19. Appendix D includes the flow exponents and coefficients used in all the reaches for both the Wenatchee River and Icicle Creek QUAL2K models.

Meteorology

QUAL2K simulates diel variations in stream temperature and water quality for a steady flow condition. QUAL2K assumes that flow remains constant but allows meteorological variables to vary with time over the course of a day. Solar radiation (and shade), air temperature, relative humidity, headwater temperature, and tributary water temperatures were specified or simulated as diurnally varying functions. Meteorological data were estimated from data recorded at stations in the Wenatchee basin. QUAL2K uses kinetic formulations for the components of the surface water heat budget described in Chapra and Pelletier (2003).

Water Quality Inputs

Headwater, tributary, and point source water quality input conditions for the QUAL2K simulations were taken from data collected during synoptic surveys, including diel temperature, DO, and pH data collected from data-loggers. Appendix C contains tables of POTW and Leavenworth National Fish Hatchery point source data collected during synoptic surveys.

The water quality characteristics of diffuse inflows (i.e., groundwater) affect the instream water quality of the Wenatchee River and Icicle Creek, particularly in the lower reaches. Calibration of the QUAL2K model involved selecting the temperature of diffuse inflows, ranging from the measured groundwater temperatures to observed surface water tributary temperatures. The groundwater DO concentration was assumed to be within the range of 6 to 12 mg/L, concentrations typically found in recently recharged groundwater (Matthess, 1982). Nutrient and chloride concentrations were selected from ranges found in Wenatchee River basin well waters. The groundwater databases of the USGS, Department of Health, and Ecology were used to develop water quality statistics for alkalinity, chloride, conductivity, nitrate, and inorganic-P (Appendix E). Groundwater water-quality statistics were developed for sub-areas which roughly corresponded to diffuse-source reach breaks in the model.

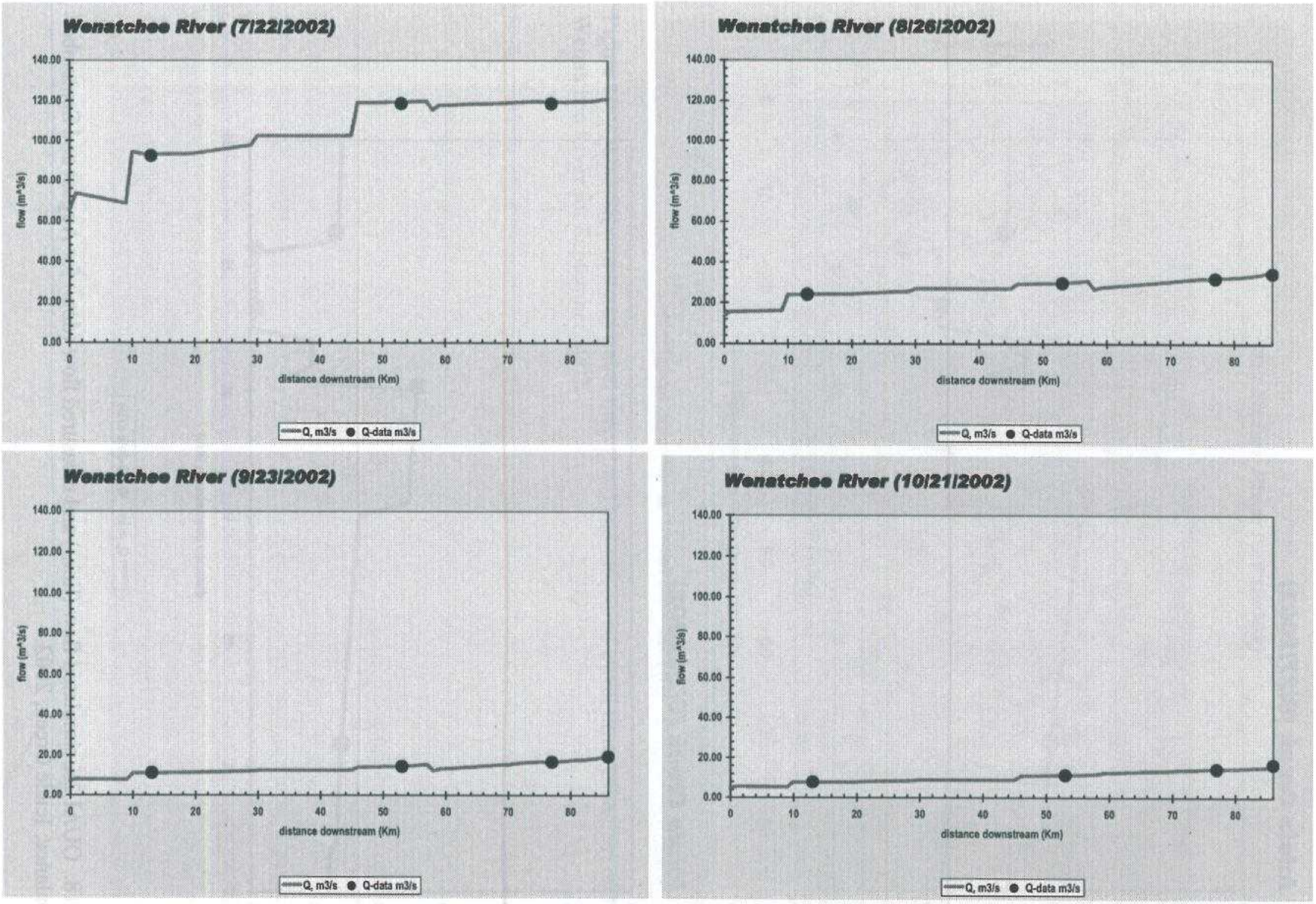


Figure 17. QUAL2K simulated flow (lines) and USGS flow (dots) for July to October flow balances; Wenatchee River, 2002.

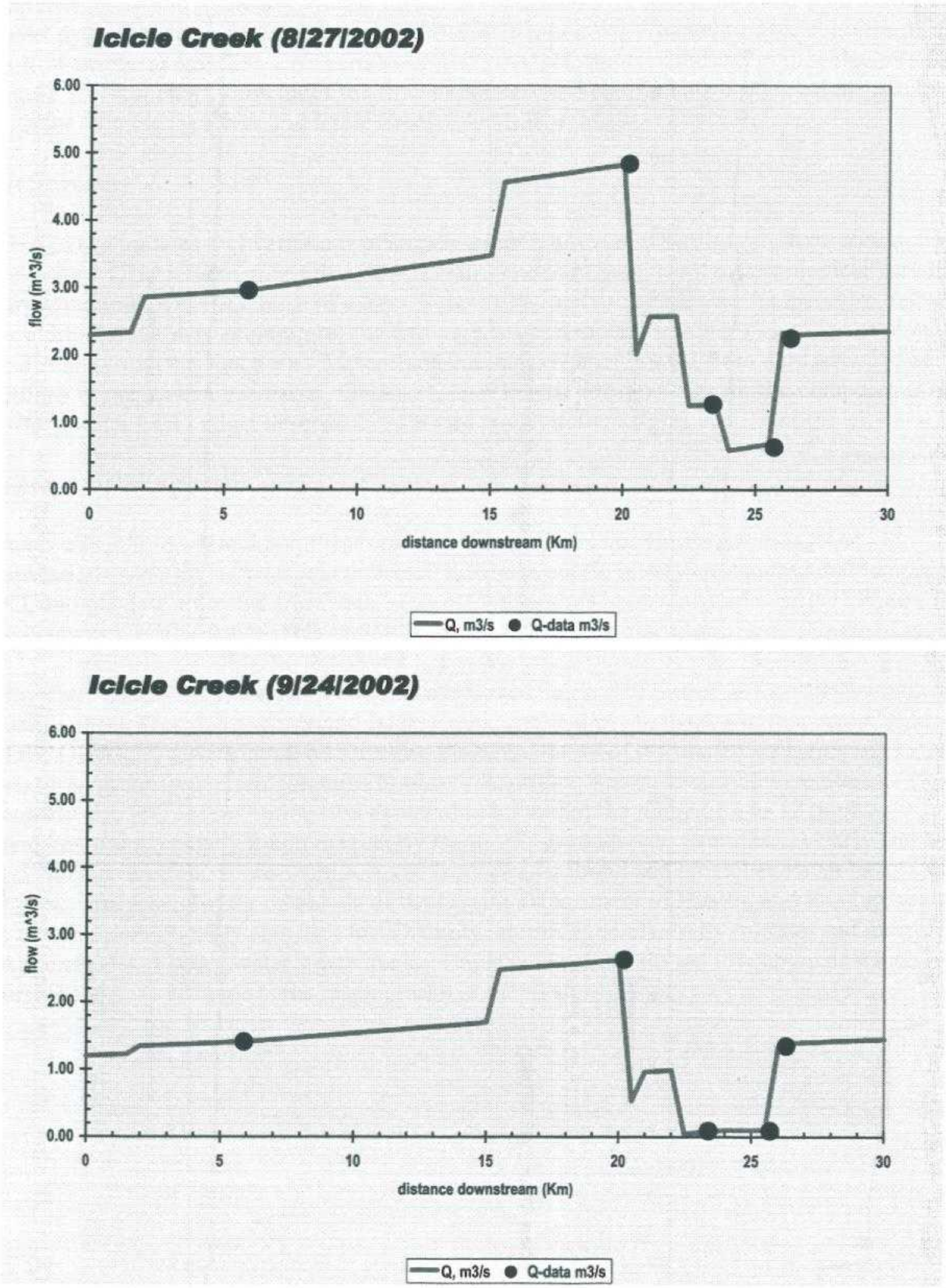


Figure 18. QUAL2K simulated flow (lines) and measured flow (dots) for August and September water balance; Icicle Creek, 2002.

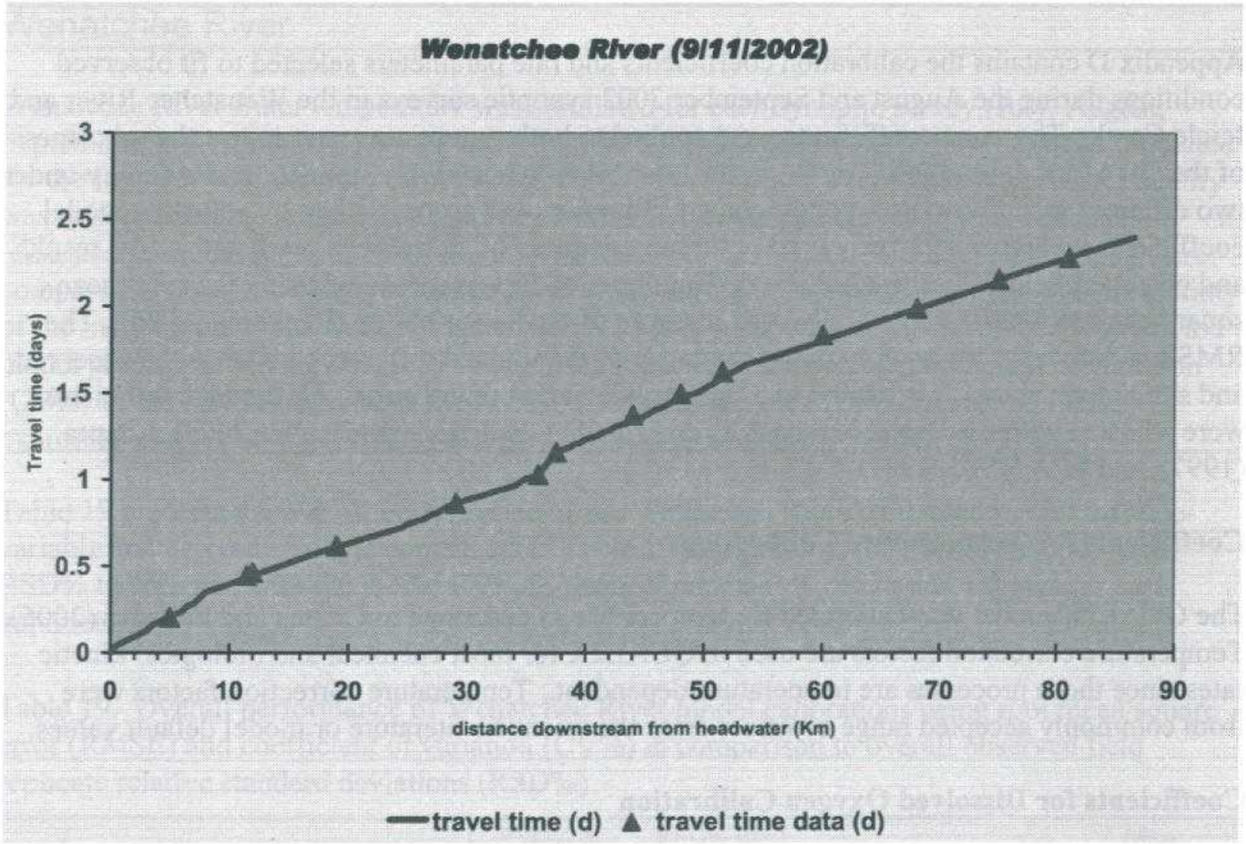


Figure 19. QUAL2K simulated travel time (line) and measured travel time (triangles) on the Wenatchee River for September 2002.

Appendix D contains the calibration coefficients and rate parameters selected to fit observed conditions during the August and September 2002 synoptic surveys in the Wenatchee River and Icicle Creek. The same coefficients were applied to both synoptic surveys to test the robustness of the QUAL2K calibration (i.e., to confirm its ability to accurately simulate water quality under two different sets of low-flow conditions). Calibration was accomplished by adjusting model coefficients and rates iteratively until optimum goodness-of-fit between predicted model results and observed field values was achieved. Goodness-of-fit was measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986). The RMSE is defined as the square root of the mean of the squared difference between the observed and simulated values. It is similar to a standard deviation of the error. All model coefficients were adjusted within acceptable ranges as described by Pelletier and Chapra (2004), Chapra (1997), and EPA (1985, 1987).

Coefficients for Temperature Calibration

The QUAL2K model was calibrated for temperature as described in Cristea and Pelletier (2005). Temperature correction factors are used in QUAL2K for most chemical and biological kinetic rates since those processes are temperature-dependent. Temperature correction factors were from commonly accepted range of values from the scientific literature or model default values.

Coefficients for Dissolved Oxygen Calibration

Various options for the calculation of atmospheric reaeration rates are available for use in the QUAL2K model. Using the guidance of EPA (1985), the Tsivoglou-Neal reaeration equation was considered to be the most representative of conditions in the Wenatchee River during the August and September synoptic surveys based on velocity and slope during low-flow conditions. For the Icicle Creek scenarios, the USGS (channel-control) equation was used.

Other DO coefficients and rate parameters, including the stoichiometric amounts of DO required per unit of ammonia nitrified or carbon oxidized, were model default values.

Coefficients for Periphyton and Nutrient Calibration

Periphyton growth was modeled using a zero-order growth rate and allowed to run until a steady-state maximum areal biomass was achieved. The simulated maximum areal biomass was calibrated to measured end-of-season biomass maxima. A variable-stoichiometry and luxury-uptake algorithm for nutrients is used in QUAL2K that separates periphyton growth from nutrient uptake. Maximum nutrient uptake rates, subsistence cell quotas, and internal half-saturation constants for algal cells, plus external nutrient half-saturation constants, were iteratively selected from published ranges summarized in Pelletier and Chapra (2004) until an optimized goodness-of-fit to the observed data was achieved.

Comparison of Observed and Simulated Water Quality in the Wenatchee River

Wenatchee River water temperature was simulated for each synoptic survey (July, August, September, and April). The conservative parameters, conductivity and chloride, were simulated for the low-flow season (July through October). The rest of the Wenatchee River water quality was calibrated to the August 2002 and September 2002 synoptic surveys. Rate constants remained the same for both calibrations. The results of the QUAL2K model simulations were compared to observed values collected by Ecology during the synoptic surveys. The uncertainty of the model predictions were estimated by the RMSE, a measure of the difference between the model prediction and the observed value. Also reported is the percent coefficient of variation (CV%) of the RMSE, defined as the RMSE divided by the mean of the observed values expressed as a percentage, similar to a percent relative standard deviation (RSD%).

Table 19 presents the overall performance of the Wenatchee River calibrated model for state-variable and derived-variable constituents. Table 19 also presents the overall field replicate RSD% to compare with the model CV% for each parameter. A discussion follows for each parameter.

Table 19. Overall performance of Wenatchee River model calibrations using root mean square error (RMSE) and coefficient of variation (CV%) in comparison to overall observed field replicate relative standard deviations (RSD%).

Parameter	Units	Reporting limit	RSD% of replicates (<5X reporting limit)	RSD% of replicates (>5X reporting limit)	RMSE of model calibration	CV% of model calibration RMSE	Mean used to calculate RMSE CV	RMSE n
Temperature	C	-	-	-	0.47	3.0%	15.6	68
Conductivity	umhos/cm	-	-	3.4%	2.7	6.5%	41.1	22
Chloride	mg/L	0.1	5.6%	4.9%	0.06	10.0%	0.6	22
DO	mg/L	-	-	1.5%	0.20	2.1%	9.6	36
pH	s.u.	-	-	0.9%	0.20	2.5%	7.9	34
Organic-P	ug/L	-	-	-	0.6	147.4%	0.4	22
Inorganic-P	ug/L	3	15.9%	0.4%	0.96	21.8%	4.4	22
Organic-N	ug/L	-	-	-	15.5	114.5%	13.5	22
Ammonia-N	ug/L	10	11.9%	2.5%	3.5	175.1%	2.0	22
Nitrate-nitrite-N	ug/L	10	2.2%	4.5%	10.9	15.7%	69.9	22
Total N	ug/L	25	16.7%	5.2%	16.3	17.6%	92.7	22
Total P	ug/L	3	15.1%	5.7%	2.1	45.5%	4.7	22

n = number

Temperature

Water temperature affects the rate of chemical and biological reactions and determines the solubility of oxygen in water. The heat budget, which determines the water temperature, is based on physical processes which can be accurately modeled by QUAL2K. The daily minimum and maximum water temperatures in the Wenatchee River were accurately simulated for each synoptic survey with an overall RMSE of 0.47 °C. Figure 20 presents a comparison of simulated and measured water temperatures for each synoptic survey.

Conservative Tracers

Chloride and conductivity were simulated in the QUAL2K models as conservative tracers (e.g., assuming no change from hydrolysis, oxidation, uptake, settling). A conservative tracer provides a good diagnostic check to see if the model is missing substantial sources or sinks of constituent mass. Missed sources are particularly evident when an incoming source concentration is greatly different than the ambient concentration in the water column, as is often the case for groundwater. Without diffuse source representation (i.e., groundwater), the QUAL2K model under-predicted chloride and conductivity concentrations, particularly in the lower Wenatchee River during low-flow months such as in September 2002 (Figure 21).

A constant mass of chloride, alkalinity, and nitrate was added to specified reaches as diffuse sources in the July, August, September, and October QUAL2K models (i.e., one set flux for all months was assumed). After assigning the fixed mass flux, chloride and conductivity were simulated with overall RMSEs of 0.05 mg/L and 2.71 umhos/cm, respectively, for the months of July through October 2002. Diffuse sources in the lower Wenatchee River accounted for 57% of the conductivity mass in the lower part of the river in the September 2002 model. Figures 22 and 23 present simulated and observed chloride and conductivity, respectively, in the Wenatchee River for July through October.

Periphyton Biomass

Periphyton biomass was simulated by comparing the model predicted biomass to the observed end-of-season biomass maxima. Samples were scraped from rocks at five locations in the Wenatchee River in the beginning of September for determination of end-of-season biomass and species densities (the periphytic mat at all sites was dominated by diatoms, primarily *Achnanthes minutissima, Achnanthes linearis,* and *Cymbella affinis,* and with *Gomphonema subclavatum* at one site). The QUAL2K models were run until a steady-state biomass was reached. Figure 24 shows the simulated biomass maxima for September 2002 versus the observed end-of-season biomass maxima.

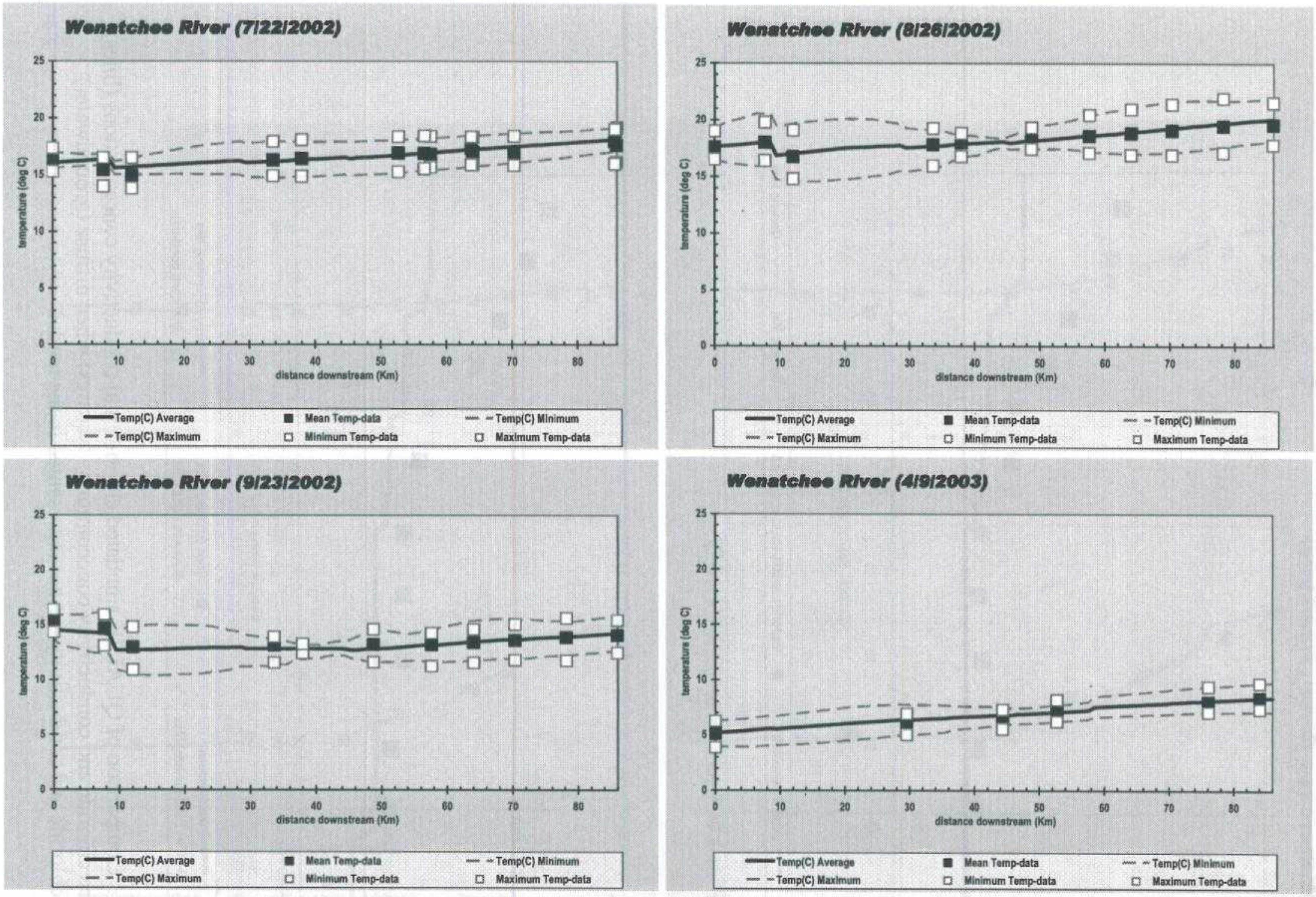


Figure 20. Comparison of QUAL2K simulated daily average water temperature (solid line) and daily maximum and minimum water temperatures (dashed lines) to observed water temperature data (squares) collected during synoptic surveys in 2002 and 2003.

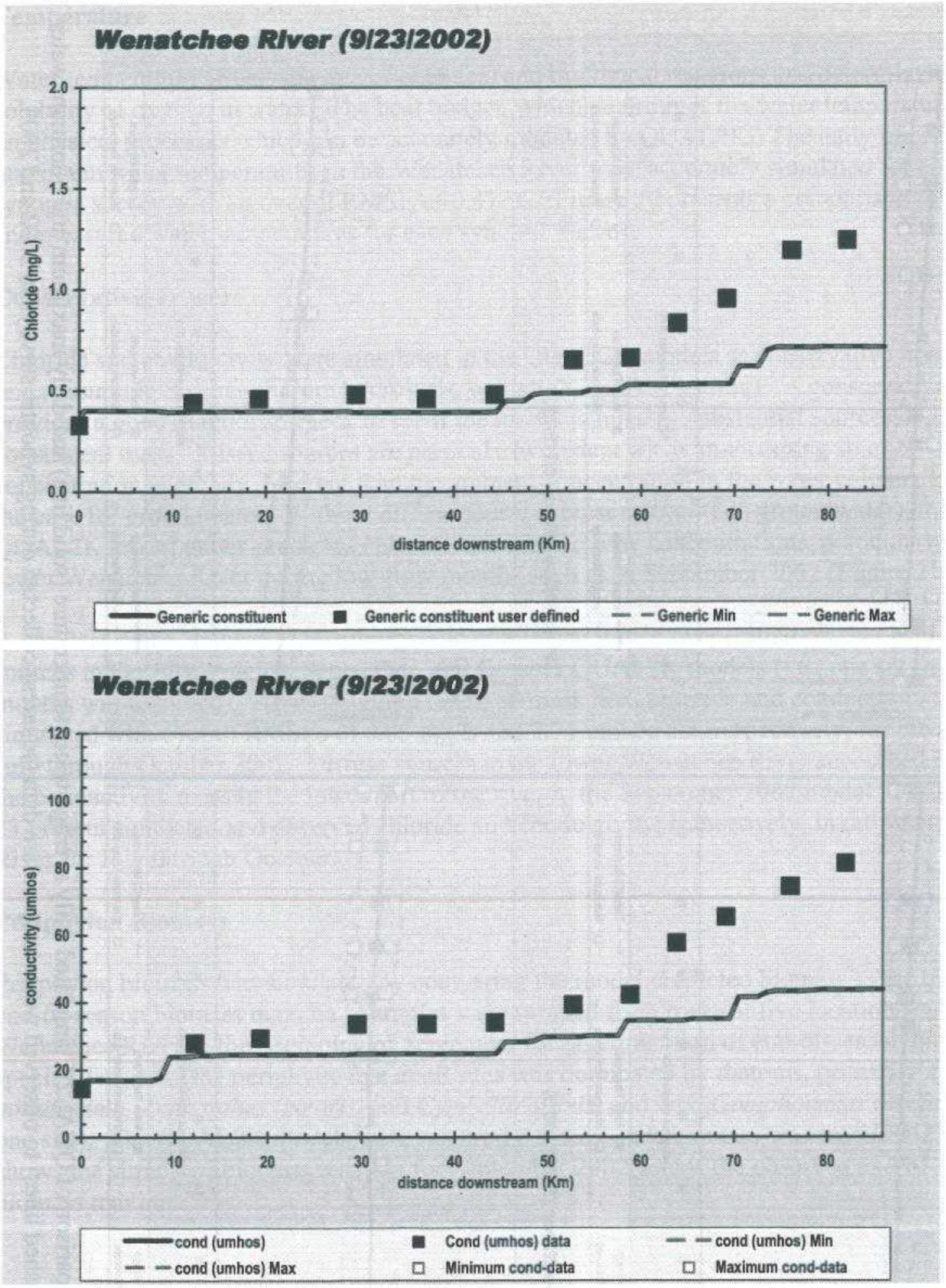


Figure 21. Comparison of QUAL2K simulated chloride and conductivity concentrations (lines) to observed chloride and conductivity concentrations (squares) when diffuse (groundwater) fluxes of chloride and conductivity are not represented in the model.

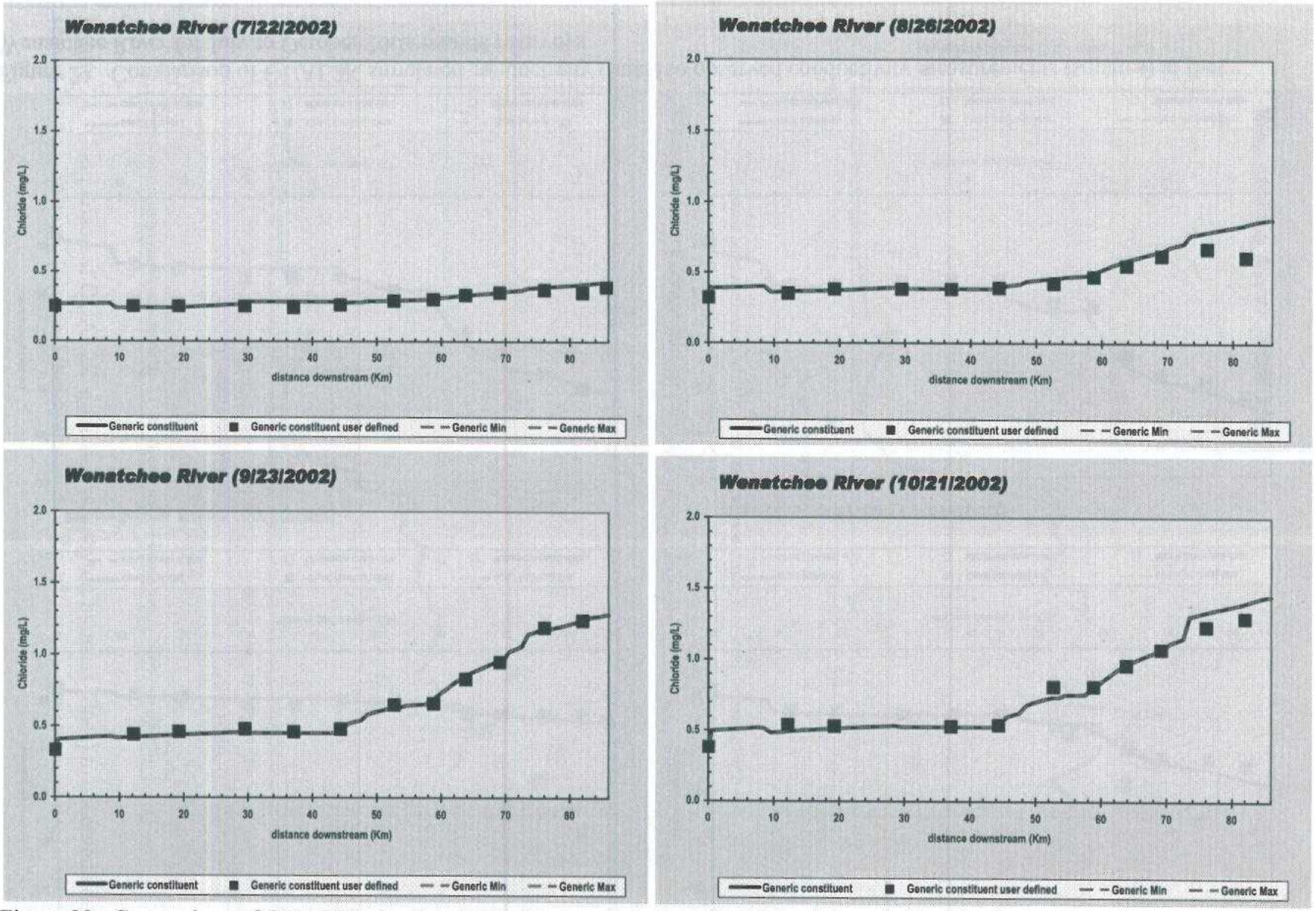


Figure 22. Comparison of QUAL2K simulated chloride concentrations (lines) to observed chloride concentrations (squares) in the Wenatchee River for July to October 2002 monthly surveys.

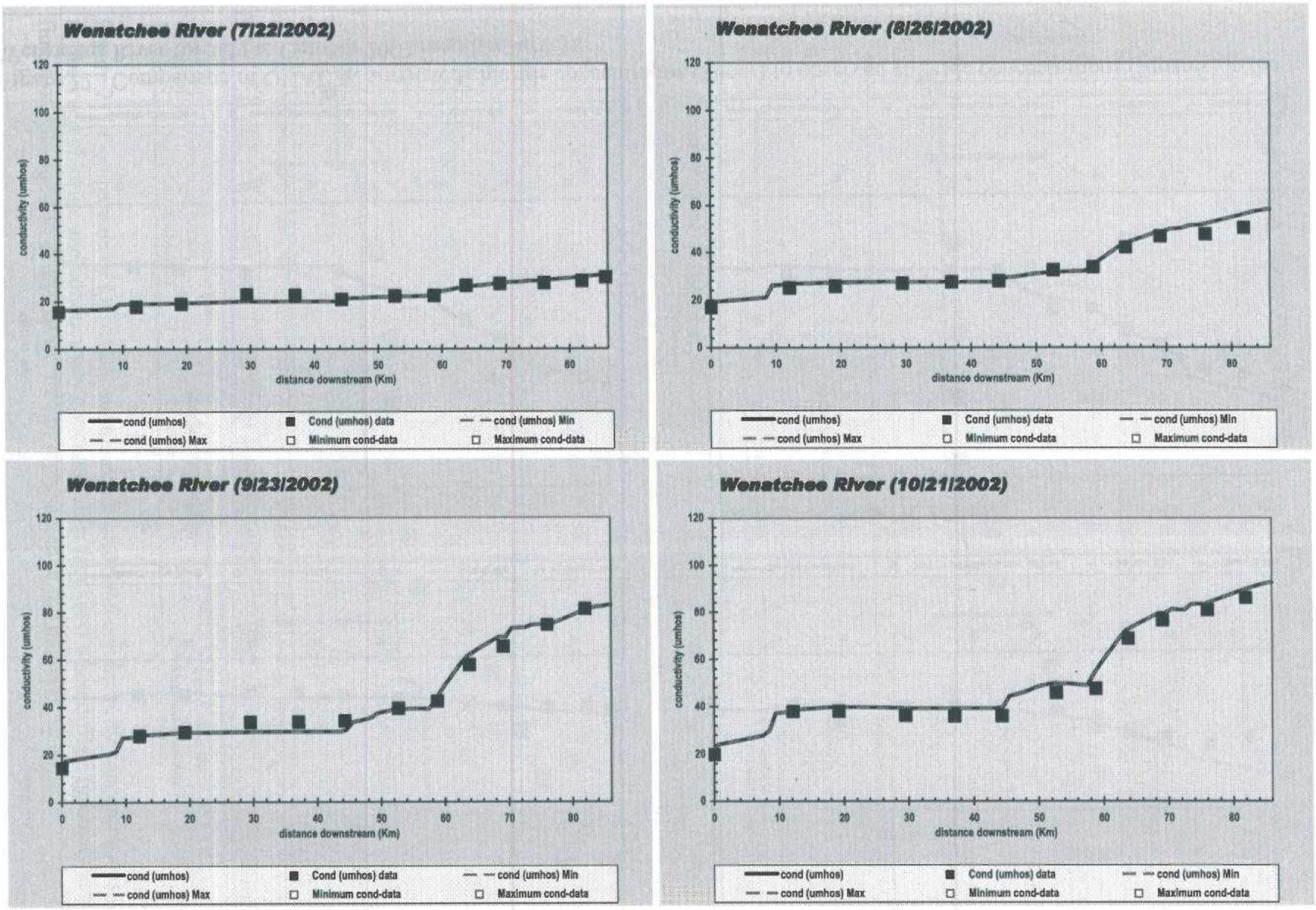


Figure 23. Comparison of QUAL2K simulated conductivity (lines) to observed conductivity measurements (squares) in the Wenatchee River for July to October 2002 monthly surveys.

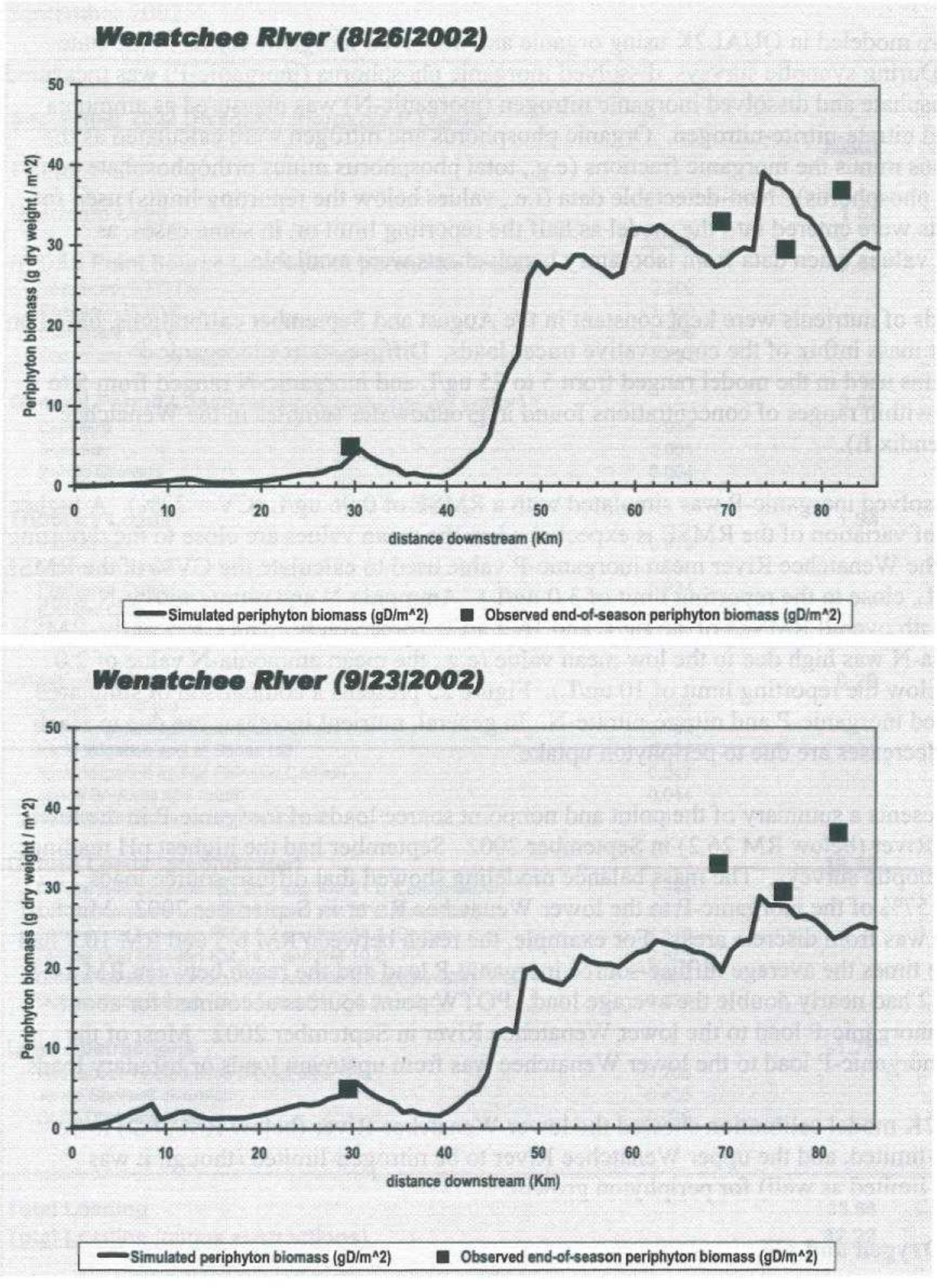


Figure 24. Comparison of QUAL2K simulated periphyton biomass (lines) to observed end-of-season biomass maxima (squares) in the Wenatchee River.

Nutrients

Nutrients are modeled in QUAL2K using organic and dissolved inorganic forms as the state variables. During synoptic surveys, dissolved inorganic phosphorus (inorganic-P) was measured as orthophosphate and dissolved inorganic nitrogen (inorganic-N) was measured as ammonia nitrogen and nitrate-nitrite-nitrogen. Organic phosphorus and nitrogen were calculated as the total fractions minus the inorganic fractions (e.g., total phosphorus minus orthophosphate equals the organic phosphorus). Non-detectable data (i.e., values below the reporting limits) used for model inputs were entered into the model as half the reporting limit or, in some cases, as uncensored values when data from laboratory bench-sheets were available.

Diffuse loads of nutrients were kept constant in the August and September calibrations, based on the constant mass influx of the conservative tracer loads. Diffuse-source inorganic-P concentrations used in the model ranged from 5 to 75 ug/L and inorganic-N ranged from 5 to 1700 ug/L, within ranges of concentrations found in groundwater samples in the Wenatchee basin (Appendix E).

Overall, dissolved inorganic-P was simulated with a RMSE of 0.96 ug/L (CV = 22%). A higher coefficient of variation of the RMSE is expected when the mean values are close to the reporting limit (e.g., the Wenatchee River mean inorganic-P value used to calculate the CV% of the RMSE was 4.4 ug/L, close to the reporting limit of 3.0 ug/L). Ammonia-N and nitrate-nitrite-N were simulated with overall RMSEs of 3.5 ug/L and 16.7 ug/L, respectively. The CV% of the RMSE for ammonia-N was high due to the low mean value (e.g., the mean ammonia-N value of 2.0 ug/L was below the reporting limit of 10 ug/L). Figure 25 presents a comparison of simulated and measured inorganic-P and nitrate-nitrate-N. In general, nutrient increases are due to reach inputs and decreases are due to periphyton uptake.

Table 20 presents a summary of the point and nonpoint source loads of inorganic-P in the lower Wenatchee River (below RM 26.2) in September 2002. September had the highest pH readings of all the synoptic surveys. The mass balance modeling showed that diffuse-source loads contributed 57% of the inorganic-P to the lower Wenatchee River in September 2002. Much of this loading was from discrete areas. For example, the reach between RM 6.5 and RM 10.8 had almost three times the average diffuse-source inorganic-P load and the reach between RM 14.1 and RM 17.2 had nearly double the average load. POTW point sources accounted for about 30% of the inorganic-P load to the lower Wenatchee River in September 2002. Most of the remaining inorganic-P load to the lower Wenatchee was from upstream loads or tributary loads.

The QUAL2K model calibration showed the lower Wenatchee River (below RM 26.2) to be phosphorus-limited, and the upper Wenatchee River to be nitrogen-limited (though it was phosphorus-limited as well) for periphyton growth.

Dissolved Oxygen and pH

Diel minimum and maximum DO in Wenatchee River were simulated with an overall RMSE of 0.20 mg/L (CV = 2.1%). The daily minimum and maximum pH were simulated with an overall RMSE of 0.20 pH s.u. (CV = 2.5%). Figure 26 presents a comparison of simulated and measured DO and pH for each synoptic survey.

Table 20. Inorganic-phosphorus loads in the lower Wenatchee River (below RM 26.2) in September 2002.

September 2002 Dissolved Inorganic-P Loads		kg/day	% of total load
Upstream Load		**1.68**	*4.96%*
	kg/day		
NPDES Point Source Loads (90th percentile loads)		**10.65**	*31.35%*
Leavenworth POTW	2.200		
Peshastin POTW	1.380		
Cashmere POTW	6.236		
Cashmere POTW lagoon leak (estimated)	0.837		
General Permit Loads (non-contact cooling water)		**0.02**	*0.06%*
Blue Bird	0.016		
Blue Star	0.001		
Bardin Growers	0.004		
Tributary Loads		**1.94**	*5.72%*
Icicle Creek	0.919		
Chumstick Creek	0.097		
Peshastin Creek	0.234		
Brender Creek	0.339		
Mission Creek	0.354		
Irrigation Spill Returns		**0.29**	*0.85%*
Cascade Orchard	0.059		
Icicle Irrigation spill near Leavenworth	0.000		
Icicle Irrigation spill at Stines Hill	0.031		
Icicle Irrigation spill at Fairview Canyon	0.047		
Jones Shotwell spill return	0.044		
Wenatchee Reclamation District spill	0.107		
Diffuse Loads (groundwater)		**19.39**	*57.06%*
Diffuse load between RM 26.2 and RM 21.0 (Leavenworth)	1.944		
Diffuse load between RM 21.0 and RM 17.2 (Peshastin)	2.684		
Diffuse load between RM 17.2 and RM 14.1 (Dryden)	4.510		
Diffuse load between RM 14.1 and RM 10.8	2.863		
Diffuse load between RM 10.8 and RM 6.5 (Cashmere)	7.049		
Diffuse load between RM 6.5 and RM 2.8 (Monitor)	0.338		
Load Abstractions		**-1.76**	
Wenatchee Reclamation District diversion	-1.269		
Jones Shotwell diversion	-0.415		
Gunn Ditch diversion	-0.079		
Total Loading		**33.98**	
Total Loading (minus abstractions)		**32.22**	

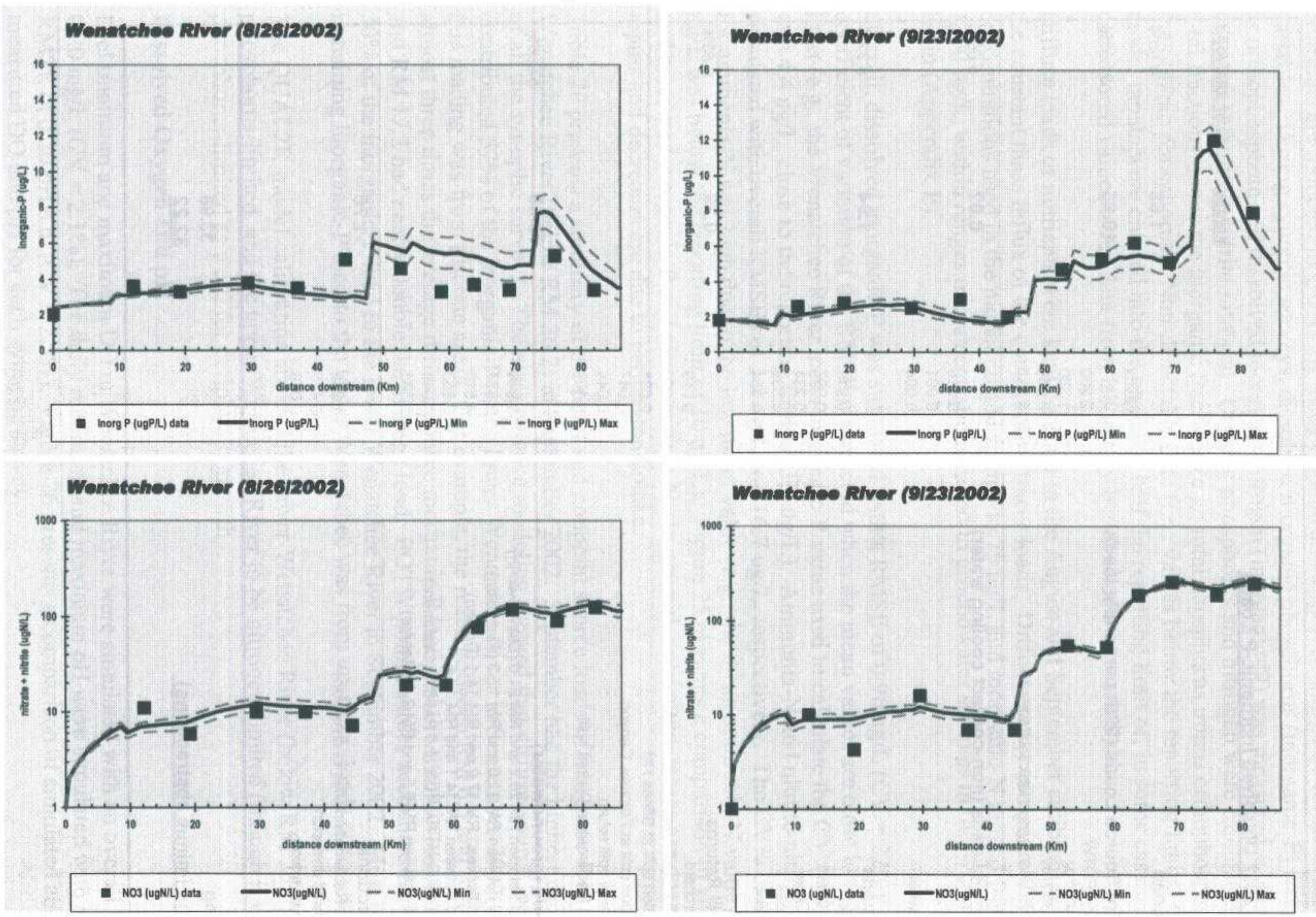


Figure 25. Comparison of QUAL2K simulated inorganic-P and nitrate-nitrite-N concentrations (lines) to observed inorganic-P and nitrate-nitrite-N concentrations (squares) in the Wenatchee River for the August 2002 and September 2002 synoptic surveys.

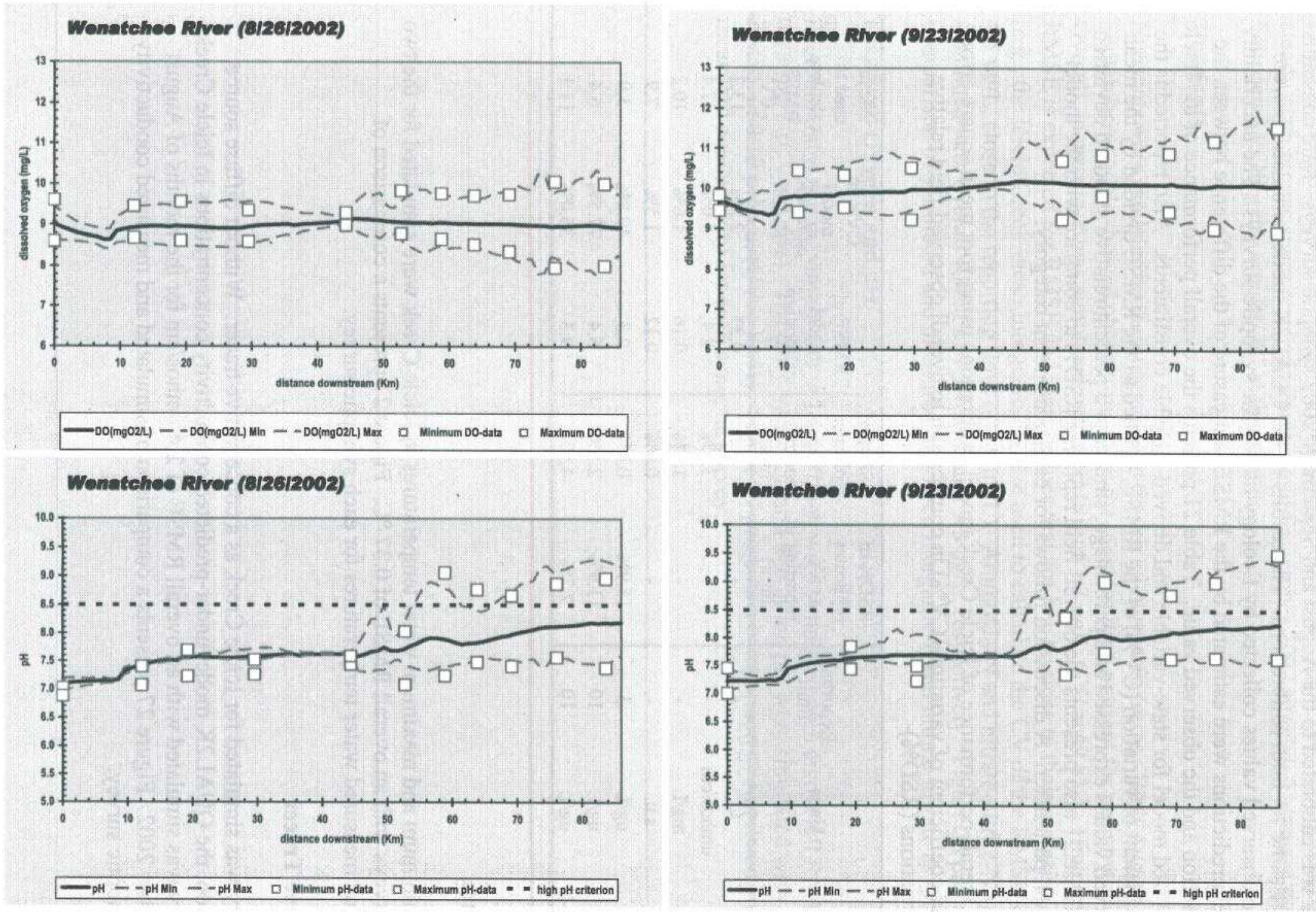


Figure 26. Comparison of QUAL2K simulated daily maximum and daily minimum dissolved oxygen and pH (dashed lines) to observed dissolved oxygen and pH (squares) in the Wenatchee River for the August 2002 and September 2002 synoptic surveys.

Comparison of Observed and Simulated Water Quality in Icicle Creek

Icicle Creek was calibrated to the August and September 2002 synoptic surveys. Rate constants remained the same for both calibrations. The results of the QUAL2K model simulations were compared to observed values collected by Ecology during the synoptic surveys. The uncertainty of the model predictions were estimated by the RMSE, a measure of the difference between the model prediction and the observed value. Table 21 presents the overall performance of the Icicle Creek calibrated model for state-variable and derived-variable constituents. Also reported is the percent coefficient of variation (CV%) of the RMSE, defined as the RMSE divided by the mean of the observed values expressed as a percentage, similar to a percent relative standard deviation (RSD%). Table 21 also presents the overall field replicate RSD% to compare with the model CV% for each parameter. A discussion follows for each constituent category.

Table 21. Overall performance of Icicle Creek model calibrations using root mean square error (RMSE) and coefficient of variation (CV%) in comparison to overall observed field relative standard deviations (RSD%)

Parameter	Units	Reporting limit	RSD% of replicates (<5X reporting limit)	RSD% of replicates (>5X reporting limit)	RMSE of model calibration	CV% of model calibration RMSE	Mean used to calculate RMSE CV	RMSE n
Temperature	C	-	-	-	0.37	2.8%	13.2	18
Conductivity	umhos/cm	-	-	3.4%	2.4	5.0%	47.4	16
DO	mg/L	-	-	1.5%	0.16	1.6%	10.2	18
pH	s.u.	-	-	0.9%	0.12	1.5%	7.9	18
Inorganic-P	ug/L	3	15.9%	0.4%	2.3	49.8%	3.9	16
Ammonia-N	ug/L	10	11.9%	2.5%	5.4	77.5%	6.4	16
Nitrate-nitrite-N	ug/L	10	2.2%	4.5%	9.3	36.0%	11.1	16

n - number

Temperature

The daily minimum and maximum water temperatures in Icicle Creek were simulated for the two synoptic surveys with an overall RMSE of 0.37 °C. Figure 27 presents a comparison of simulated and measured water temperatures for each synoptic survey.

Conservative Tracer

Conductivity was simulated for Icicle Creek as a conservative tracer. Without diffuse source representation, the QUAL2K model under-predicted conductivity concentrations in Icicle Creek. Conductivity was simulated with an overall RMSE of 2.4 umhos/cm for the months of August and September 2002. Figure 27 presents a comparison of simulated and measured conductivity for each synoptic survey.

Periphyton Biomass

Periphyton biomass was not sampled for Icicle Creek. The Icicle Creek model was run until a steady-state biomass was reached. August and September 2002 simulated biomass maxima were between 8 to 10 g dry weight/ m^2 at the mouth.

Nutrients

Nutrients were modeled as their organic and dissolved inorganic forms. Both August and September models showed phosphorus to be the most limiting nutrient for periphyton growth. Overall, inorganic-P was simulated with a RMSE of 2.3 ug/L (CV = 49.8%). Higher CV of the RMSE is expected for RMSE and mean values that are low or close to their reporting limit (e.g., the Icicle Creek mean inorganic-P value used to calculate the CV of the RMSE was 4.5 ug/L, close to the reporting limit of 3.0 ug/L). Ammonia-N and nitrate-nitrite-N were simulated with overall RMSEs of 5.4 ug/L and 9.3 ug/L, respectively. Figure 28 presents a comparison of simulated and measured dissolved inorganic-P and nitrate-nitrate as nitrogen.

Dissolved Oxygen and pH

Diel minimum and maximum DO in Icicle Creek were simulated with an overall RMSE of 0.16 mg/L (CV = 1.6%). The daily minimum and maximum pH were simulated with an overall RMSE of 0.12 pH s.u. (CV = 1.5%). Figure 29 presents a comparison of simulated and measured conductivity for each synoptic survey.

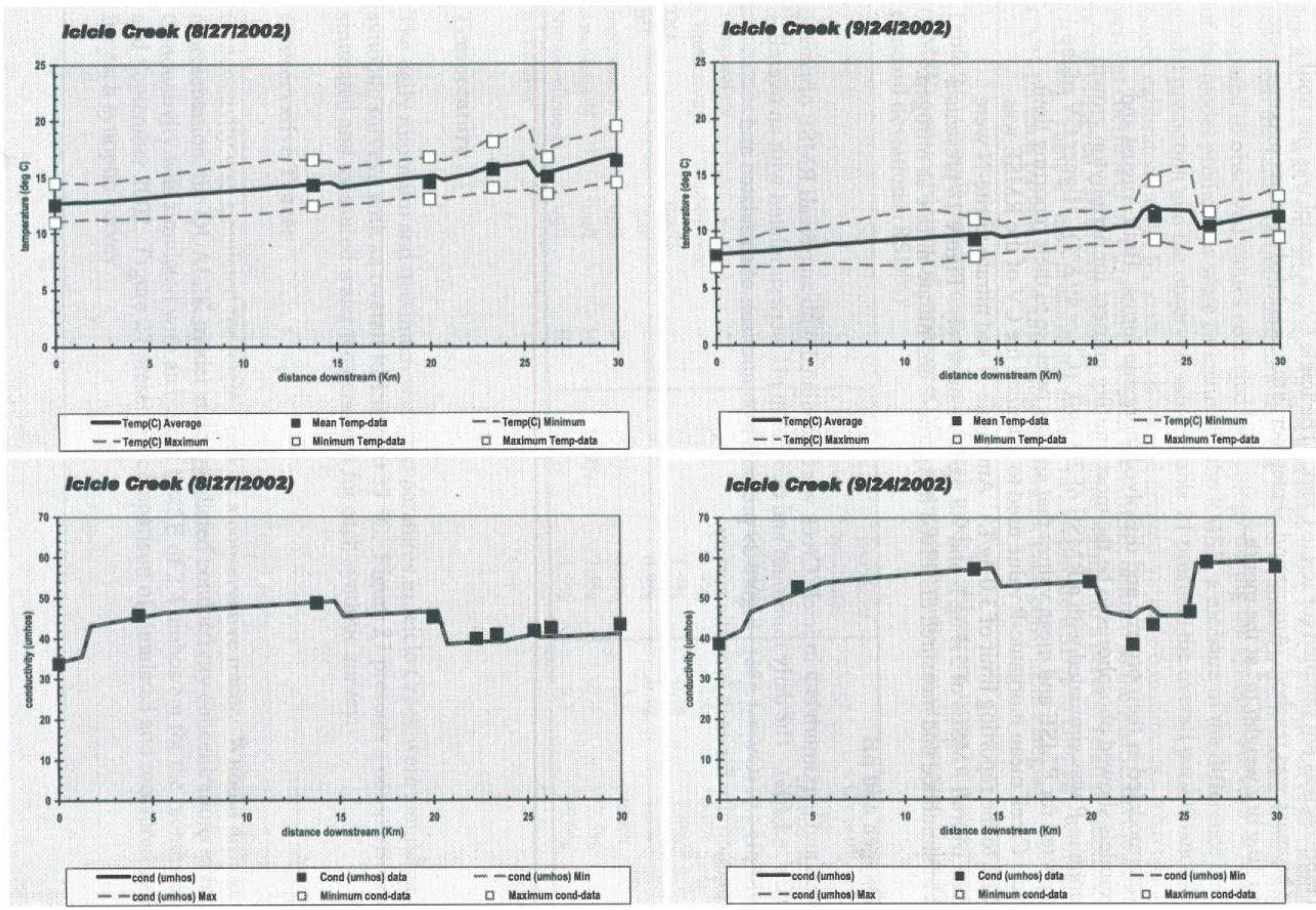


Figure 27. Comparison of QUAL2K simulated water temperature and conductivity (lines) to observed water temperature and conductivity (squares) in Icicle Creek for the August 2002 and September 2002 synoptic surveys.

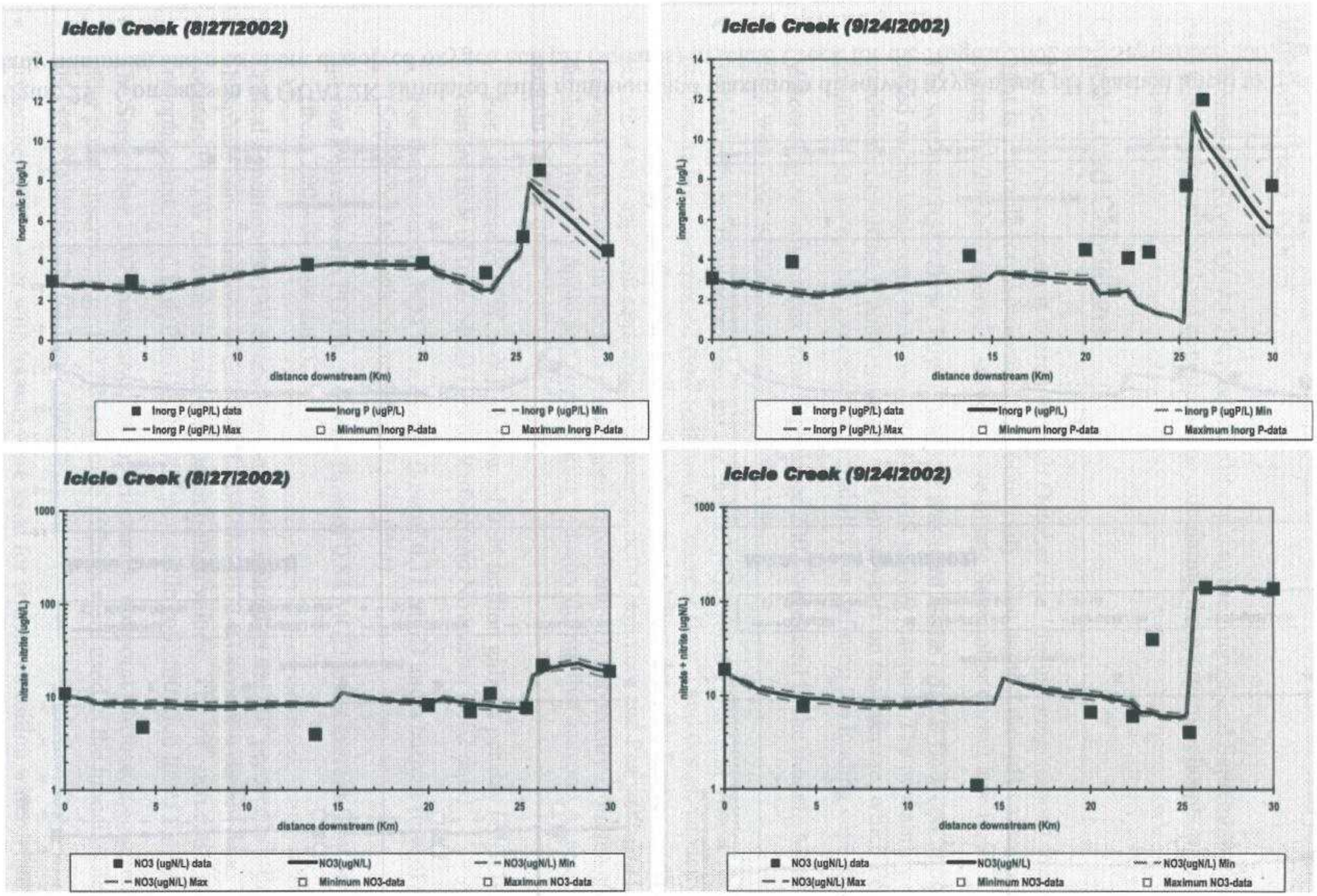


Figure 28. Comparison of QUAL2K simulated dissolved inorganic-P and nitrate-nitrite-N (lines) to observed dissolved inorganic-P and nitrate-nitrite-N (squares) in Icicle Creek for the August 2002 and September 2002 synoptic surveys.

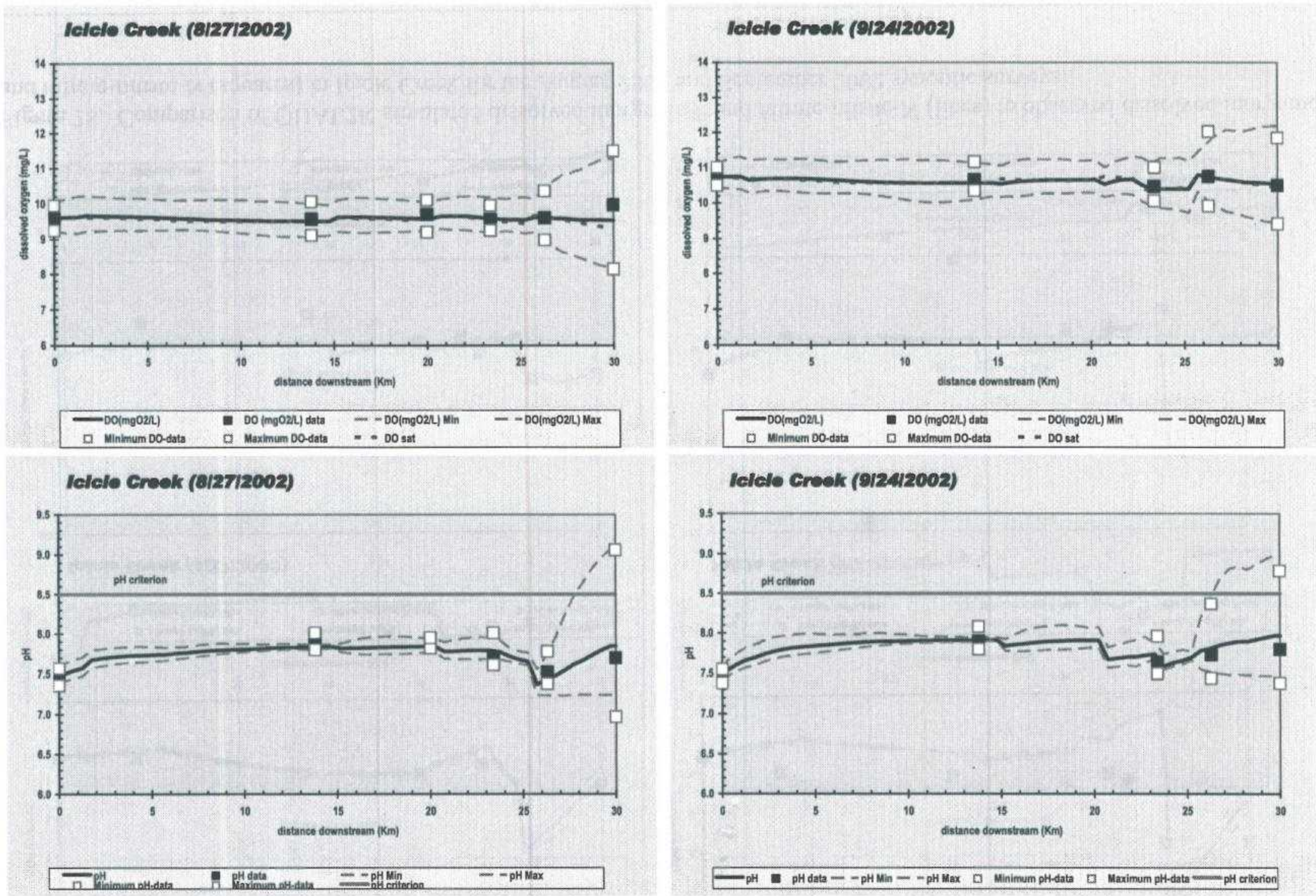


Figure 29. Comparison of QUAL2K simulated daily minimum and maximum dissolved oxygen and pH (dashed lines) to observed daily minimum and maximum dissolved oxygen and pH (squares) in Icicle Creek for the August 2002 and September 2002 surveys.

Assimilative Load Capacity for Phosphorus

Wenatchee River

The Wenatchee River QUAL2K model (calibrated to the August and September 2002 data) was used to simulate critical-load conditions for calculating the inorganic-phosphorus assimilative load capacity.

Critical Load Conditions

- The season of concern is March through October (i.e., the growing season) when enough light is available for photosynthetic productivity. The highest diel pH values measured during the 2002-03 synoptic surveys were in late September during low-flow.
- The seasonal 7Q10 flow (July – October) was used as the critical flow condition and was based on the long-term flow records of USGS gaging stations. The probability of 7Q10 conditions occurring is approximately one in ten years on the average, which Ecology considers an acceptable exceedance probability for defining the loading capacity.
- Meteorological conditions from September 2002 were used in the model. Meteorology for 2002 was close to representing a median year.
- Critical effluent flow conditions for the Publicly-Operated Treatment Works (POTWs) were defined as highest-reported flow (defined as "current flow") and design-capacity flow (defined as "design flow"). In the recently reported flow data, the Leavenworth POTW did not show any apparent seasonality; however, both Cashmere and Peshastin POTWs showed seasonal high flows in the fall (September to November), apparently from the additional discharge from the apple and pear packing industry during that season. Appendices B and C contain POTW data.
    1. For Cashmere POTW, a design flow of 0.94 million gallons per day (MGD) and a current flow of 0.66 MGD (from October and November 2002 data).
    2. For the Peshastin POTW, a design flow of 0.11 MGD and a current flow of 0.061 MGD (September through November 2003-04 data).
    3. For Leavenworth POTW, a design flow of 0.84 MGD and a current flow of 0.43 MGD (from 2003-04 flow data).
- Critical-condition POTW concentrations were defined as the 90th percentile effluent orthophosphate concentrations as calculated from the 2002-03 synoptic survey data. Appendix C contains POTW data tables with the concentration values. The 90th percentile current orthophosphate load is defined as the 90th percentile concentration times the current flow.
- The September 2002 concentrations for tributaries, nonpoint (diffuse; e.g., groundwater), and other point (discrete; e.g., POTWs) source inflows were used in the model. They represent the best available data for these sources.
- September 2002 water withdrawals were used for critical-condition water withdrawals.

Load Capacity for the Lower Wenatchee River

A simplified first-approximation of the assimilative capacity for inorganic-P was developed by reducing the inorganic-P load from all sources (point and nonpoint) by an equal percentage, until the predicted maximum diel pH did not exceed the 8.5 pH criterion in any part of the lower river. All of the remaining inorganic-P loads to the lower Wenatchee River were then added together to give a single assimilative capacity.

A single assimilative capacity for the whole lower Wenatchee is a simplification because it treats the whole lower reach as if it were a single compliance point. However, it provides a first approximation of the scale of reduction needed to comply with water quality standards. In reality, there are many discrete compliance points throughout the lower Wenatchee River, and there are many possible combinations of loadings that would meet water quality standards at each compliance point. The QUAL2K model has a resolution of one kilometer segments. The model will be used to evaluate alternative load-reduction scenarios, which is outside the scope of this report.

Using the simplified approach to establish a single assimilative capacity for the whole lower Wenatchee River, the model showed a maximum assimilative capacity of 7.8 kg/day of inorganic-P loading to comply with the water quality standards during critical conditions. At this point, the maximum instream inorganic-P concentration in the river was 3.1 ug/L, representing the target inorganic-P total maximum daily load (TMDL) concentration.

An 80% reduction in inorganic-P loading from all sources would be necessary to comply with water quality criteria. Ecology does not consider this simplified method (e.g., 80% from all sources) as a viable allocation strategy, because the required reductions from some sources would result in inorganic-P levels below natural background levels or below levels of what might be expected with any kind of reasonable assurance. In addition, because there is more inorganic-P loading in the lower end of the lower Wenatchee River, a larger percent reduction is necessary in that part of the river than in the upper end of the lower Wenatchee River.

Table 22 compares the critical inorganic-P loads with current POTW flows to the assimilative capacities for inorganic-P in the lower Wenatchee River (below RM 26.2). Mass balance modeling showed that under critical conditions and with current POTW flows and treatment levels, 49% of the inorganic-P load to the lower Wenatchee is from diffuse sources, 43% of the inorganic-P load is from the three POTWs (including the Cashmere lagoon leak), and nearly 5% is from the tributaries, for a total inorganic-P load of almost 40 kg/day entering the lower Wenatchee. Only 1.3 kg/day of inorganic-P is expected from upstream sources. At design flow conditions and current treatment levels, the POTW's inorganic-P load to the lower Wenatchee is expected to increase to 44 kg/day (Table 23).

Table 22. Critical-condition loads and assimilative capacity for inorganic-P in the lower Wenatchee River during critical low-flow conditions and current POTW effluent discharge.

Critical-Condition Dissolved Inorganic-P Loads	kg/day	kg/day	% of total load
Upstream Load		**1.24**	3.2%
NPDES Point Source Loads (90th percentile loads)		**16.78**	42.7%
Leavenworth POTW	7.557		
Peshastin POTW	1.609		
Cashmere POTW	6.780		
Cashmere POTW lagoon leak (estimated)	0.837		
General Permit Loads (non-contact cooling water)		**0.02**	0.1%
Blue Bird	0.016		
Blue Star	0.001		
Bardin Growers	0.004		
Tributary Loads		**1.75**	4.4%
Icicle Creek	0.802		
Chumstick Creek	0.097		
Peshastin Creek	0.153		
Brender Creek	0.339		
Mission Creek	0.354		
Irrigation Spill Returns		**0.29**	0.7%
Cascade Orchard	0.059		
Icicle Irrigation spill near Leavenworth	0.000		
Icicle Irrigation spill at Stines Hill	0.031		
Icicle Irrigation spill at Fairview Canyon	0.047		
Jones Shotwell spill return	0.044		
Wenatchee Reclamation District spill	0.107		
Diffuse Loads (groundwater)		**19.23**	48.9%
Diffuse load between RM 26.2 and RM 21.0 (Leavenworth)	1.944		
Diffuse load between RM 21.0 and RM 17.2 (Peshastin)	2.583		
Diffuse load between RM 17.2 and RM 14.1 (Dryden)	4.478		
Diffuse load between RM 14.1 and RM 10.8	2.856		
Diffuse load between RM 10.8 and RM 6.5 (Cashmere)	7.036		
Diffuse load between RM 6.5 and RM 2.8 (Monitor)	0.335		
Load Abstractions		-2.39	
Wenatchee Reclamation District diversion	-1.869		
Jones Shotwell diversion	-0.439		
Gunn Ditch diversion	-0.083		
Total Loading		**39.31**	
Total Loading (minus abstractions)		**36.92**	

Dissolved Inorganic-P Assimilative Capacity	**7.76** *kg/day*
Excess Dissolved Inorganic-P Loading	**29.16** *kg/day*

Table 23. Critical-condition inorganic-phosphorus loads for the POTWs in the lower Wenatchee River at design flow and capacity POTW effluent discharge.

NPDES Municipal Point Source (design flow) in the lower Wenatchee River	Inorganic-P Load (kg/day)
Leavenworth POTW (0.84 MGD)	18.7
Peshastin POTW (0.11 MGD)	3.7
Cashmere POTW (0.94 MGD)	21.3
Total for Lower Wenatchee POTWs (1.89 MGD)	43.7

Table 22 clearly shows that large reductions of inorganic-P loads are necessary from point and nonpoint sources. Currently, POTWs account for nearly 43% of the inorganic-P load in the lower Wenatchee River during critical conditions. With future growth or expansion of services up to their design capacities, the POTWs are expected to account for up to 67% of the inorganic-P load.

Based on mass-balance modeling, diffuse nonpoint sources account for nearly half of the inorganic-P load to the lower Wenatchee River during critical conditions. Inorganic-P loads conveyed by groundwater to the river appear to be the main source of diffuse inorganic-P. The groundwater water-quality characteristics may be influenced by infiltration from the surrounding irrigated agricultural regions, rural and urban development (on-site septic and wastewater collection systems), land application of waste and process water, and other unidentified sources. There may be naturally occurring phosphorus sources as well.

One possible diffuse phosphorus source is leaching from on-site septic drainfields. A study of Lake Chelan in Chelan County (Patmont et al., 1989) found that septic system discharges of phosphorus to the lake were greatest in areas where saturated soils predominated beneath on-site drainfields. In the soils around Lake Chelan, an unsaturated zone extending more than 3 meters below the saturated drainfield was recommended for optimum phosphorus-removal efficiency. A similar study is recommended for the different soil types in the Wenatchee Basin to determine the minimal depth of unsaturated soils beneath drainfields for effective removal of phosphorus. Development and implementation of regulations that restrict placement of drainfields from areas with inadequate unsaturated soils would likely result in reduction of nonpoint phosphorus to the river.

Mass-balance modeling showed that two reaches of the lower Wenatchee River had two to three times the diffuse P-loading of other reaches (Table 22). Of these reaches, one brackets the city of Dryden, and the other brackets the city of Cashmere. High levels of inorganic-P and nitrate (e.g., ranges of 79-250 ug/L of orthophosphate and 2-3.5 mg/L of nitrate) were found in groundwater samples taken from piezometers located below Dryden's community drainfield. This drainfield is located on a point of the riverbank and is a likely source of high nutrients in the groundwater, although other upland land use practices, such as the land application of process water by the local fruit processors, may contribute as well. In the Cashmere reach, estimates of the leaching from the Cashmere wastewater lagoon may be low due to limited data; there may be increased diffuse loading of inorganic-P from the lagoon. Other potential contributors of inorganic-P to groundwater in and around the city of Cashmere include on-site septic, leaking wastewater collection systems, and other unidentified sources. There may be naturally occurring phosphorus sources as well. Both reaches may provide an opportunity for significant nonpoint reduction of inorganic-P. Groundwater phosphorus source studies and best management practices (BMP) implementation are recommended in both of these reaches.

Tributaries account for nearly 5% of the inorganic-P load to the lower Wenatchee River during critical conditions. Even though Icicle Creek had lower inorganic-P concentrations, the largest load was from Icicle Creek because it had the highest flow of all the lower tributaries. In 2002, Peshastin Creek and Icicle Creek had inorganic-P concentrations less than 10 ug/L at their mouths. The mouth of Mission Creek had some inorganic-P concentrations above 10 ug/L, and Brender Creek and Chumstick Creek generally had inorganic-P concentrations above 20 ug/L. With the exception of Icicle Creek, nutrient sampling was conducted only at the mouths of the tributaries in 2002.

Brender, Mission, and Chumstick creeks also had fecal coliform bacteria, dissolved oxygen, and pH water quality violations. Implementing control measures to mitigate fecal coliform exceedances in these tributary basins will likely mitigate dissolved oxygen and pH exceedances by lowering nutrient concentrations. Further nutrient sampling is recommended for Brender, Mission, and Chumstick creeks to identify nutrient sources in those watersheds.

Storm runoff is infrequent during the low-flow months of August through October (the main critical season). While the water quality of a large storm runoff event has not been characterized, summer thunderstorms that produce large, localized runoff events may temporarily affect water quality in streams and the river. Infrequent storm runoff cannot be modeled in a steady-state fashion and was not included in the QUAL2K modeling of the Wenatchee River; however, it is recommended to control and manage any stormwater runoff from agricultural lands, urban areas, and/or transportation corridors by using BMPs to reduce stormwater impacts to surface waters. Storm runoff and snowmelt runoff is most important in the early growing season from March through May.

Reserve Load Capacity for the Upper Wenatchee River

In Class AA reaches of the Wenatchee River, dissolved oxygen (DO) concentrations were shown to be less than the 9.5 mg/L criterion during the summer months due to high land elevations and high water temperatures. Implementation of the Wenatchee River temperature TMDL will improve DO; however, to stay in compliance with water quality standards, future biochemical oxygen demand (BOD) and nutrient loading from point and nonpoint sources needs to be restricted to keep from reducing minimum diel DO more than the allowable 0.2 mg/L from natural conditions. Additionally, future nutrient loading needs to be restricted in Class AA waters to keep from increasing the diel pH range more than 0.2 pH units from natural conditions. The calibrated Wenatchee River model was used to determine reserve load capacities for BOD and nutrients during critical conditions.

To determine the nutrient load capacity, nutrient loading was increased at the Lake Wenatchee POTW discharge location (RM 53.3) in the Wenatchee River model (set to critical conditions) until the simulated DO and pH were out of compliance with water quality standards. Modeling showed that the upper Wenatchee River is currently co-limited by nitrogen and phosphorus (nitrogen is the most limiting) but is poised to respond readily to additional nutrient loading. To maintain water quality standards, a reserve load capacity of 1.35 kg/day of additional (above current conditions) inorganic-N or 0.17 kg/day of inorganic-P load is recommended at the reach where the Lake Wenatchee POTW discharges. This reserve capacity represents a total capacity for all sources in the reach, both point and nonpoint. Currently, the Lake Wenatchee POTW has a permit for only seasonal winter-time discharge to the Wenatchee River and land-applies during the summer critical season. Controlling diffuse (nonpoint) sources will be critical to protecting the water quality of the upper Wenatchee River. The QUAL2K model can be used to ensure that impacts from various additional loads in other parts of the river do not combine in a way such that compliance is exceeded at any point in the river.

The current instream concentrations of inorganic-phosphorus and inorganic-nitrogen in the upper Wenatchee River during the low-flow months of August to October were used as natural reference conditions. They are at or below reporting limits (3.0 ug/L and 10.0 ug/L, respectively), representing conditions that currently comply with water quality standards and probably nearly reflect natural conditions (as far as can be determined). In order to preserve the pristine water quality of the upper Wenatchee River, the Lake Wenatchee POTW or any other point source should not discharge to the Wenatchee River at any time during March through October. The summer-time land application site for the POTW should be checked for adequate unsaturated soils (i.e., static water levels greater than 3 meters below ground surface) for high-level phosphorus removal, and monthly phosphorus sampling (with a reporting limit down to 3 ug/L) should be included in the POTW groundwater monitoring plan. The Wenatchee National Forest wastewater infiltration pond for the Tumwater Campground off Highway 2 should be checked for proper functioning. Since nitrates are difficult to trap in soil, a conversion to an evaporation pond or some other treatment option other than infiltration should be explored for the campground facility.

As mentioned for the lower Wenatchee River, development and implementation of regulations that restrict placement of on-site septic drainfields from areas with inadequate unsaturated soils would preserve the upper Wenatchee River pristine water quality. Estimates could be made of the maximum number and density of on-site drainfields that the upper basin could accommodate and still meet the water quality standards, as was done in the Lake Chelan study (Patmont et al., 1989).

Icicle Creek

The calibrated Icicle Creek QUAL2K model was used to predict diel pH response to variable phosphorus loads during conditions similar to the September and August 2002 synoptic surveys.

Critical Load Conditions

- The season of concern in Icicle Creek is July through October when enough light is available for photosynthetic productivity, flows are low, and water temperatures are warm enough for productivity. The highest diel pH values (and only exceedances) measured in Icicle Creek during 2002-03 were at the mouth of the creek during the August and September synoptic surveys.

- The seasonal 7Q10 flow (July –October) at the mouth had to be estimated because there is no long-term flow record at the mouth and significant water diversions occur below the upstream USGS gaging station. Based on limited data, the seasonal 7Q10 flow at the mouth was estimated to be close to the September 2002 measured flow (i.e., within 7 cfs or 0.2 cms of each other). During this time of year, most of the flow originates from the Leavenworth National Fish Hatchery (LNFH) outflow. Most of the hatchery outflow is water from their upstream Icicle Creek diversion; however, the hatchery augments the Icicle Creek water diversion with water from a well-field to provide adequate flow for the facility. The ability to augment flow presumably creates consistent year-to-year flow conditions at the mouth. The September 2002 flow was assumed to represent 7Q10 conditions.
- Meteorological conditions from September 2002 were used in the model. The meteorology for 2002 was close to a median year representation.
- The September 2002 loads from the hatchery main outflow and abatement pond discharge, as well as the calculated diffuse loads in lower Icicle Creek, were used in the model. They represent the best available data for these sources.

Load Capacity for Icicle Creek

Assimilative capacity for inorganic-phosphorus was determined by reducing loading from the hatchery main outfall and abatement pond effluent until water quality standards were met. For September 2002, most of the flow and the inorganic-P load in lower Icicle Creek came from the hatchery main outfall. Table 24 compares the current inorganic-P loads with the assimilative capacities for inorganic-P in lower Icicle Creek (below RM 4.1) for the September simulation. The simulation showed phosphorus to be the most limiting nutrient for periphyton growth. The September 2002 simulation, which is assumed to represent critical conditions, predicted an assimilative capacity of 0.65 kg/day of inorganic-P in the lower part of Icicle Creek, requiring a 55% load reduction of current loads.

Table 24. Critical-condition (September 2002) loads and assimilative capacity for inorganic-P in the lower Icicle Creek during critical low-flow conditions (September 2002 flows).

Critical-Condition Dissolved Inorganic-P Loads	kg/day	kg/day	% of total load
Upstream Load		**0.01**	*0.8%*
Point Source Loads		**1.25**	*86.3%*
Leavenworth National Fish Hatchery (main outfall)	1.191		
Leavenworth National Fish Hatchery (abatement pond discharge)	0.062		
Diffuse Loads		**0.19**	*12.9%*
Diffuse load between RM 2.9 (hatchery) and RM 2.3 (E. Leavenworth Rd.)	0.061		
Diffuse load between RM 2.3 and mouth	0.126		
Total Loading		**1.45**	
Dissolved Inorganic-P Assimilative Capacity		**0.65**	***kg/day***
Excess Dissolved Inorganic-P Loading		**0.80**	***kg/day***

To attain water quality standards in lower Icicle Creek, the hatchery main outfall would need to reduce its inorganic-P effluent concentration to less than 5.0 ug/L. The inorganic-P concentration in the hatchery main outfall was approximately 13 ug/L in both August and September 2002, a three-fold increase over the inorganic-P concentration of the intake water from its upper Icicle Creek diversion. (The maximum 2002-03 inorganic-P concentration in Icicle Creek above the old channel (RM 3.9) was less than 5.0 ug/L and averaged 3.4 ug/L). Organic-P concentrations in the main outfall were below reporting limits. There were significant observed increases (200% to 1500% increases) in ammonia and nitrate concentrations in the main outfall discharge compared to the below-reporting-limit levels of the Icicle Creek water at the hatchery diversion. An increase in inorganic-P and ammonia within the hatchery facility is most likely due to the products of fish metabolism and phosphorus addition from fish feed, although groundwater augmentation may contribute additional phosphorus and nitrogen (the hatchery well water was not sampled).

Kendra (1989) summarized the work of numerous investigators who documented water quality degradation downstream of fish hatcheries, including increased downstream algal and periphyton growth and productivity.

The assimilative capacities predicted for September (critical conditions) resulted in a maximum instream inorganic-P (orthophosphate) concentration of 4.4 ug/L which represents the target inorganic-P total maximum daily load (TMDL) concentration.

Margin of Safety

The Clean Water Act requires a margin of safety (MOS) to be incorporated into the loading capacity. The MOS requirement is intended to account for uncertainty in data and modeling. The MOS may be implicit (built into the analysis) or explicit (an added, separate load allocation).

The MOS for this study was implicitly provided by using a combination of conservative modeling assumptions that tend to err on the side of a smaller loading capacity (e.g., combining 7Q10 flow conditions with 90th percentile pollutant loads and hot, meteorological conditions favorable for stream productivity).

The Wenatchee River point-source dischargers experience greater loading during critical low-flow conditions due to increased loads from the fruit packing industry in the fall. Therefore, in the course of establishing wasteload and load allocations, an additional explicit MOS (10%) is recommended to be applied for the TMDL.

Conclusions

The Wenatchee River and Icicle Creek are on the 1998 303(d) list of impaired waters for pH and dissolved oxygen. Ecology conducted monthly synoptic surveys in the Wenatchee River and Icicle Creek during the season of concern, July through September 2002, and during April 2003.

In Class AA reaches, dissolved oxygen concentrations were shown to be lower than the 9.5 mg/L criterion during the summer due to high land elevations and high water temperatures.

pH data showed that the upper pH criterion of 8.5 was exceeded near the mouth of Icicle Creek and in the lower Wenatchee River from RM 21.0 (above Peshastin) to the mouth. The cause of the pH exceedances was from periphyton (attached algae) growth. Nitrogen-to-phosphorus ratios of instream bioavailable nutrients suggest that dissolved inorganic phosphorus (inorganic-P) is the most limiting nutrient that controls periphyton growth.

Steady-state modeling of dissolved oxygen, pH, and periphyton productivity, based on EPA's QUAL2K model, was conducted to evaluate the capacity of the Wenatchee River and Icicle Creek to assimilate dissolved inorganic-P loading from point and nonpoint sources and still meet water quality criteria.

The Wenatchee River QUAL2K model showed that inorganic-P was limiting periphyton growth in the lower Wenatchee River. Modeling of critical conditions in the lower Wenatchee River showed an assimilative capacity of 7.7 kg/day of inorganic-P, which represents an 80% reduction from current loading conditions. The model also showed that the assimilative capacity for the lower Wenatchee River can also be represented by an instream maximum inorganic-P concentration of 3.1 ug/L.

Under critical conditions and with current publicly-owned treatment works (POTW) flows and treatment levels, nearly 50% of the inorganic-P load to the lower Wenatchee is from diffuse sources, 43% is from the three POTWs (including the Cashmere lagoon leak), and nearly 5% is from tributaries, for a total load of nearly 40 kg/day. Large reductions of inorganic-P are needed from both point and nonpoint sources to meet the assimilative capacity of the lower Wenatchee River.

Mass-balance modeling showed that two reaches of the lower Wenatchee River exhibit higher diffuse phosphorus loading than other reaches. Of these reaches, one brackets the city of Dryden and the other brackets the city of Cashmere. Groundwater studies should be done in these two reaches, specifically focusing on which land uses in these reaches are causing phosphorus inputs to the river.

Tributaries account for nearly 5% of the inorganic-P load to the lower Wenatchee River during critical conditions. The largest load was from Icicle Creek because it had the highest flow of the lower tributaries. With the exception of Icicle Creek, nutrient sampling was conducted only at the mouths of the tributaries during 2002. Mission, Brender, and Chumstick creeks generally had higher inorganic-P concentrations, in addition to fecal coliform bacteria, dissolved oxygen, and pH water quality violations. Implementing control measures to mitigate fecal coliform exceedances in these tributary basins will likely mitigate dissolved oxygen and pH exceedances by lowering nutrient concentrations. Further nutrient sampling is recommended for Brender, Mission, and Chumstick creeks to identify nutrient sources in those watersheds.

To maintain water quality standards in the upper Wenatchee River, reserve load capacities for biochemical oxygen demand (BOD) and nutrients are recommended. The Lake Wenatchee POTW should not discharge to the Wenatchee River during March through October, and the land application site for the POTW and any future on-site drainfields should be checked for adequate unsaturated soils for high-level phosphorus removal.

The Icicle Creek QUAL2K model showed that inorganic-P was limiting periphyton growth in the lower Icicle Creek (below RM 4.1). Mass-balance modeling showed that under critical conditions, most of the inorganic-P loading (over 85%) to lower Icicle Creek was from the Leavenworth National Fish Hatchery main outfall. The model also showed that the assimilative capacity for inorganic-P in lower Icicle Creek was 0.65 kg/day which represents a 55% reduction from current levels. The assimilative capacity for lower Icicle Creek can also be represented by an instream maximum inorganic-P concentration of 4.4 ug/L. Under critical conditions, inorganic-P concentrations in the Leavenworth National Fish Hatchery main outfall effluent must be below 5 ug/L to meet the assimilative capacity of the creek.

The Wenatchee River and Icicle Creek are very sensitive to the addition of nutrients. Although phosphorus levels are relatively low (less than 20 ug/L) compared to other Washington State streams, they are currently too high in the lower reaches to comply with the pH water quality standards.

Recommendations

In Class AA reaches, dissolved oxygen concentrations were shown to be less than the 9.5 mg/L criterion during the summer months due to high land elevations and high water temperatures. Implementation of the Wenatchee River Temperature Total Maximum Daily Load (TMDL) will improve dissolved oxygen in the river and tributaries; however, to be in compliance with water quality standards, future biochemical oxygen demand (BOD) and nutrient loading needs to be restricted to keep from further reducing minimum diel dissolved oxygen more than 0.2 mg/L from natural conditions. Additionally, future nutrient loading needs to be restricted to prevent the diel pH range from increasing more than 0.2 pH units from natural conditions.

To maintain water quality standards in the upper Wenatchee River, reserve load capacities for BOD and nutrients are recommended. The Lake Wenatchee Publicly-Owned Treatment Works (POTW) should not discharge to the Wenatchee River during March through October, and the land application site for the POTW and any future on-site drainfields should be checked for adequate unsaturated soils for high-level phosphorus removal.

In Class A reaches of the Wenatchee River, large reductions of phosphorus are currently needed from both point (discrete) and nonpoint (diffuse) sources to meet the assimilative capacity of the lower Wenatchee River. An allocation plan for phosphorus wasteload and load allocations needs to be developed.

Mass-balance modeling showed that two reaches of the lower Wenatchee River exhibit higher diffuse phosphorus loading than other reaches. Of these reaches, one brackets the city of Dryden and the other brackets the city of Cashmere. Groundwater studies should be done in these two reaches, specifically focusing on which land uses are causing phosphorus inputs to the river.

The Icicle Creek QUAL2K model showed that most of the inorganic-phosphorus loading (over 85%) to lower Icicle Creek is from the Leavenworth National Fish Hatchery main outfall. Under current critical conditions, inorganic-phosphorus concentrations in the Leavenworth National Fish Hatchery main outfall effluent must be below 5 ug/L to meet the assimilative capacity of the creek.

Adaptive Management Process

The Wenatchee River Basin TMDL study included a partnership between the Department of Ecology and the Water Resource Inventory Area (WRIA) 45 Water Quality Technical Subcommittee (WQTS). The WQTS consists of Ecology TMDL staff and the WRIA 45 Watershed Planning Unit's Water Quality Subcommittee.

Ecology authored this TMDL technical report for dissolved oxygen, pH, and phosphorus, and the WQTS reviewed, discussed, and commented on the report.

The data collection and literature review conducted for and presented in this technical report for the Wenatchee River basin represent the current state of knowledge for dissolved oxygen and pH in the watershed. It is the understanding of the WQTS that additional studies will be performed to fill data gaps and address unanswered questions, as determined by the WQTS.

Conclusions and recommendations currently presented in this technical report may be revised based on new data as they become available. It is also the understanding of the WQTS that any new data gathered from further study can be incorporated in the TMDL process in the *Summary Implementation Strategy* (SIS) or *Detailed Implementation Plan* (DIP) wherein recommendations and management strategies may be refined. This adaptive management approach is acceptable to both Ecology staff and the WQTS. Ecology will partner with stakeholders (interested parties) in the watershed to conduct studies addressing information gaps (e.g., monitoring).

Further monitoring for purposes of TMDL assessment will be addressed in the TMDL SIS and DIP. Any new science available as a result of these studies will be integrated into the SIS and DIP as new conclusions and management recommendations. Management strategies addressing both point (discrete) and nonpoint (diffuse) pollution sources are subject to this adaptive management approach.

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Appendices

Appendix A

Publicly-Owned Treatment Works, Permit Limits and Background

by Steven Golding

Leavenworth POTW

The NPDES Permit No. WA-002097-4 for the City of Leavenworth Publicly-Owned Treatment Works (POTW) became effective May 1, 2005, and expires April 30, 2010. Discharge is to the Wenatchee River.

Effluent Limitations[a]: Outfall # 001		
Parameter	Average Monthly	Average Weekly
BOD5	30 mg/L; 210 lbs/day 85% minimum removal	45 mg/L; 315 lbs/day
Total Suspended Solids	30 mg/L; 210 lbs/day 85% minimum removal	45 mg/L; 315 lbs/day
Fecal Coliform Bacteria	200/100 mL	400/100 mL
pH	Shall not be outside the range of 6.0 – 9.0	

[a] The average monthly and weekly effluent limitations are based on the arithmetic mean of the samples taken, with the exception of fecal coliform which is based on the geometric mean.

Schedule of TMDL Compliance: The Permittee shall be in compliance with assigned wasteload allocations by July 14, 2014.

The City of Leavenworth operates wastewater collection and treatment facilities serving residential and commercial customers within the city limits of Leavenworth. In recent years the treatment plant reached, and on occasion exceeded, its design capacity. In addition, the city determined that the treatment plant did not have the capability to meet receiving water standards for toxic constituents. In addition, the collection system was found to have several major deficiencies, with portions over 50 years old and reaching the end of their service life. Finally, a significant population growth for the city was projected over the next 20 years, suggesting a further demand on wastewater services.

In response, the city prepared a *Wastewater Facilities Plan* in 1996. The plan recommended a comprehensive program of collection system rehabilitation and maintenance, including separation of storm sewers from the sanitary sewer system, and expansion and upgrade of the treatment plant, including an improved sludge management program, ultraviolet (UV) disinfection, and enhanced treatment capacities. Improvements in the *Facilities Plan* were based on a 20-year planning horizon (1995 to 2015), when the service population is predicted to increase from 2020 to 4483.

Between 1971 and 1973, a major project was undertaken to separate stormwater flows from the sanitary wastewater flow by constructing a separate storm sewer system. The *Facility Plan* has addressed deficiencies in the collection system, and the city signed a contract to implement a TV inspection of the system to identify areas of needed repair or replacement.

The Leavenworth POTW has been upgraded. Before the upgrade, the plant consisted of headworks, two oxidation ditch aeration basins, two secondary clarifiers, chlorination facilities, and discharge to the Wenatchee River. With the new POTW, wastewater processing begins with an anoxic conditioning tank, or selector, to improve sludge settling characteristics. The wastewater is then processed by a new oxidation ditch aeration basin, followed by secondary clarification and UV disinfection, before being discharged to the Wenatchee River.

The process for the current permit included a preliminary evaluation of the discharge's potential for exceedance of the water quality standards for ammonia. Based on this preliminary evaluation, the discharger does not have a reasonable potential for exceedance of the water quality standards for ammonia. Nitrification (oxidation of ammonia) is expected to occur in the normal course of biological treatment in the plant, especially in warmer seasons. The permit recommends that the plant operator implement necessary actions to maintain optimum plant nitrification during the critical period.

Peshastin POTW

Permit No. WA-005217-5 for Chelan County PUD No. 1, Community of Peshastin POTW became effective January 1, 2005, and expires on December 31, 2009. Discharge is to the Wenatchee River.

Effluent Limitations: Outfall # 001		
Parameter	Average Monthly[a]	Average Weekly[b]
BOD5	30 mg/L; 27.5 lbs/day	45 mg/L; 41.25 lbs/day
Total Suspended Solids	30 mg/L; 27.5 lbs/day	45 mg/L; 41.25 lbs/day
Fecal Coliform Bacteria	200/100 mL	400/100 mL
pH	Shall not be outside the range of 6.0 – 9.0	

[a] The average monthly effluent limitation is defined as the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

[b] The average weekly effluent limitation is defined as the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.

Schedule of TMDL Compliance: The Permittee shall be in compliance with assigned wasteload allocations no later than ten years after the permit is issued.

The Peshastin Wastewater Treatment Plant (or POTW) serves the unincorporated community of Peshastin and two fruit packing facilities near the plant. There have been plans to provide service to an additional industrial site being developed adjacent to the POTW. In the past, chemical additives used by the fruit packers have interfered with the treatment plant's ultraviolet disinfection process, causing exceedances of its fecal coliform effluent limits. The fruit packers decided to conduct an engineering study to correct their pretreatment problems.

Wastewater from residences receives preliminary treatment in a septic tank effluent pumped (STEP) system. Preliminary treatment occurs on-site at each residence, since the septic tank acts as a primary clarifier. Most of the solids remain in the septic tank; therefore, smaller diameter sewer lines are used, and the main treatment plant does not require grit chambers, bar screens, or other unit processes typically associated with headworks.

Flows entering the main treatment plant are first pretreated by caustic soda or pre-chlorination injection systems, if necessary. The caustic soda system is used to maintain effluent pH above 6.0. The treatment plant is designed to nitrify wastewater (oxidize ammonia). During the nitrification process, wastewater alkalinity is consumed. Once all or most of the alkalinity is consumed, nitrification is diminished and the wastewater is subject to rapid changes in pH. During operation of the caustic injection system, the operator must closely monitor ammonia levels and effluent pH. The purpose of the pre-chlorination system is to minimize toxicity and odors caused by hydrogen sulfide in the influent, a common occurrence with pressurized collection systems.

The treatment plant uses a sequential batch reactor (SBR) system to provide secondary treatment. Two SBR systems react independently, with only one operated during seasons of lower influent flow. Each SBR follows a four-phase process that combines aeration and clarification in the same basin, thereby eliminating the need for separate clarifiers and return activated sludge pumps. Each SBR can also be converted for ammonia, phosphorus, or nitrogen removal by altering the aeration and settling sequences. After leaving the SBRs, the effluent passes in front of ultraviolet lamps for final disinfection. The plant has two sludge digesters. During normal operation, the SBR system is completely automated, although the operator must monitor process control parameters to ensure the system processes are working effectively.

Cashmere POTW

Permit No. WA-002318-3 for the City of Cashmere POTW was issued January 22, 2001, became effective March 1, 2001, and expired February 28, 2006. The final limitations, shown in the table below, began on July 1, 2003, lasting through February 28, 2006. Discharge is to the Wenatchee River.

Effluent Limitations: Outfall # 001		
Parameter	Average Monthly	Average Weekly
BOD5	45 mg/L, 354 lbs/day and 65% minimum removal	65mg/L, 511 lbs/day
Total Suspended Solids	75 mg/L, 590 lbs/day	112 mg/L, 880 lbs/day
Fecal Coliform Bacteria	200/100 mL	400/100 mL
pH	Shall not be outside the range of 6.0 – 9.0	
Additional Effluent Limitations: Outfall # 001		
Parameter	Average Monthly	Daily Maximum
Total Residual Chlorine	Minimized	0.05 mg/L, 0.4 lbs/day
Total Ammonia	To be determined	To be determined

The Cashmere POTW provides wastewater collection and treatment for a combination of residential, commercial, and industrial contributors. Industrial users are Tree Top, Inc, a fruit processing facility, two fruit packing facilities, and Liberty Orchards, makers of applets and cotlets candies.

The facility provides secondary treatment with a three-cell lagoon system, chlorine disinfection, and dechlorination. The city also operates a Bulk Volume Fermenter (BVF) for pretreatment of fruit processing wastes.

The city had intermittent compliance problems during the permit period beginning 1995 as a result of algal blooms in the lagoons. In the late autumn of 1999, the city installed baffles and a cover over the final lagoon, which, according to the current fact sheet, appears to have eliminated compliance problems related to algal blooms. The fact sheet states that the city has been adding hydrochloric acid to control pH, and notes that suspended solids cannot be easily controlled, exceeding permit limits three to four months of the summer and early fall.

During the current 2002-2003 Wenatchee TMDL sampling events, some samples were noticeably green and the lagoons continue to produce a high pH effluent at times. City personnel continue to add acid to the effluent seasonally to bring pH to within permit limits.

The permit issued in 2001 requires compliance with the established effluent limits and self-monitoring to verify compliance: two Infiltration and Inflow Evaluations, two Wasteload Assessments, and a new Operation and Maintenance Manual.

In 1999, the city requested an amendment to its urban growth boundary. The annexation added approximately 96 acres to the west of the city, including the Chelan County Fairgrounds. The annexation resulted in a 30% increase in the population projections contained in the 1995 *Comprehensive Sewer Plan*. In November 1999, the Department of Ecology received an amendment to the plan which describes measures the city took to accommodate the expanded wastewater service area. These measures include construction of the West Cashmere Lift Station and the addition of 4.5 miles of sewer pipe. The amendment to the plan was approved by Ecology in November 1999. Expansion of the collection system was completed in September 2000.

A *Facility Plan* was written in response to an Administrative Order issued by Ecology in 1995. The order noted that the city's treatment facilities had neared or exceeded NPDES permitted influent and discharge capacities on a number of occasions, and required the city to submit a plan to maintain adequate capacity.

The city's facility planning is being undertaken in two phases, Phases I and II, to cover a 20-year planning horizon. Planned improvements include replacement of the lift station, removal of stormwater discharges, installation of a cover over lagoon #3, installation of a dechlorination system, and implementation of a groundwater monitoring program. These had been accomplished at the time of permit issuance, with the groundwater monitoring program in development.

The *Facility Plan* does not offer specifics regarding Phase II, other than stating that the process will begin as the facility approaches 85% of design capacity. Phase II is said to involve a major upgrade concerning the capacity and leakage of the lagoons. Design criteria (2000-2005) include 0.943 MGD combined maximum month flow rate, 11,200 lbs/day combined BOD to lagoon system (from both municipal and BVF).

The following BVF pretreatment wastewater characterization table, based on data from November 1997 through October 1998, is from the current fact sheet:

Parameter	Influent			Effluent		
	Annual Average	Lowest Monthly Average	Highest Monthly Average	Annual Average	Lowest Monthly Average	Highest Monthly Average
Flow (MGD)	0.245	0.045	0.332	NR	NR	NR
BOD_5 (lbs/d)	5,731	501	8,776	34.9	10	74
TSS (lbs/d)	2,519	166	3,649	333.1	19	992
pH range	NR			Low pH = 6.2 High pH = 8.1		

NR – Not Reported

During this 12-month period, BOD removal rates for the BVF ranged from 98% to nearly 100%. TSS removal rates were not as consistent, ranging from 67% to 96%, but were generally 85% or better. Average BOD effluent concentrations ranged from 7 to 27 mg/L, with concentrations usually between 13 and 18 mg/L. TSS concentrations varied significantly, ranging from 51 to 432 mg/L, but most often running between 100 and 250 mg/L.

The current permit contains a Schedule of Compliance requiring the city to sample effluent ammonia concentrations and receiving water temperature and pH to provide the Department of Ecology with sufficient data to conduct a reasonable potential analysis. In the event reasonable potential is determined, other than accepting permit limits for ammonia, the city has the option of doing an Effluent Mixing Zone Study.

Chelan County Public Utility District #1 Town of Dryden POTW

Permit No. ST-5562 for the Chelan County PUD #1 Town of Dryden POTW was issued August 3, 2000, became effective September 1, 2000, and expired August 31, 2005. The permit allows discharge to groundwater via percolation. The permit stipulates the following numerical limitations:

Effluent Limitations: Outfall # 0001	
Parameter	Daily Maximum
Flow	0.023 MGD
Biochemical Oxygen Demand (5 day)	230 mg/L*
Total Suspended Solids	150 mg/L*
pH	Shall not be outside the range of 6.0 to 9.0

* Before discharge to the drainfields

The Chelan County Public Utility District (PUD) #1 constructed the Town of Dryden POTW in the summer of 1981 as a septic tank/drainfield treatment system. The system was designed to serve 60 connections. No expansion or rehabilitation of major facilities is currently scheduled. However, capacity of the plant will be required to be monitored as the connected population increases over the years.

The treatment facilities consist of two 23,000 gallon concrete septic tanks, a splitter box, three drainfield trenches comprising 1.37 acres, and two 841-gallon dosing tanks. The drainfield pipe is 4-inch diameter perforated, designed to distribute 1.1 gallons per square foot per day.

The permit fact sheet states that the wastewater receives anaerobic and then aerobic treatment, "which is considered an excellent way to disinfect wastewater prior to discharge back to groundwater near the Wenatchee River. Once the drainfield oxidants and reductants have been consumed by the river flora and fauna, only the non-nutrient salts will remain in the waters of the Wenatchee River."

Typically, only two drainfields are loaded at any time with the third left to rest, giving the plan a hydraulic design capacity of 23,000 gallons per day. The fact sheet states that "while resting, a drainfield breathes and fully oxidizes any ammonia that has been deposited in the soil." The remaining two drainfields operate continuously during the resting period of one year. The fact sheet does not assess the potential for unoxidized ammonia to percolate into the river from the two active drainfields.

Discharge flow from the plant is determined by noting the count of tank drainages. Dave Johnston of the PUD indicated that flow distribution between the two active tanks has been erratic at times, and the PUD has not been able to improve plant operation in this respect. He also pointed out a fruit packer about 200 feet uphill from the POTW. The fruit packer was spray irrigating what may have been process water at the time of Ecology's September 2002 visit.

The fact sheet states that the gravel and cobble-filled soils of the drainfield will be difficult to assess. Monitoring from two wells was required until Ecology determined the data were not of value in assessing the plant discharge (Dave Holland/ WQ/ CRO, personal communication, 2002). The permit required a Plan for Maintaining Adequate Capacity and an Infiltration and Inflow Evaluation, both to be submitted by March 1, 2003.

Lake Wenatchee POTW

Permit No. WA-005209-4 for Lake Wenatchee POTW became effective May 1, 2005, and expires April 30, 2010. The permit allows discharge to the Wenatchee River from September 1 through April 30 of the following year, not to exceed eight consecutive months. The permit stipulates the following numerical limitations:

Effluent Limitations: Outfall # 0001		
Parameter	Average Monthly[a]	Daily Limitation[b]
BOD5	10 mg/L; 3.9 lbs/day	10 mg/L; 3.9 lbs/day
Total Suspended Solids	10 mg/L; 3.9 lbs/day	10 mg/L; 3.9 lbs/day
Fecal Coliform Bacteria	50/100 mL	230/100 mL
Dissolved Oxygen (DO) Min.	N/A	2.8 mg/L
pH	Shall not be outside the range of 6.5 to 8.5	

[a] The highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month. The daily discharge is calculated as the average measurement of the pollutant over the day.

[b] The greatest allowable value for any calendar day for all parameters except DO. The Permittee is required to maintain a minimum effluent concentration of 2.8 mg/L of DO at all times.

Schedule of TMDL Compliance: The Permittee shall be in compliance with assigned wasteload allocations by July 14, 2014.

The permit stipulates that discharge to a sprayfield be limited only to April 1 through September 30 of each year, the period not exceeding six consecutive months. The permit stipulates the following numerical limitations:

Effluent Limitations: Sprayfield		
Parameter	Average Monthly[a]	Average Weekly[b]
Soluble BOD	20 mg/L; 8.67 lbs/day	30 mg/L; 13 lbs/day
Total Suspended Solids	45 mg/L; 19.5 lbs/day	67.5 mg/L; 29.3 lbs/day
Fecal Coliform Bacteria	50 colonies/100 mL	200 colonies/100 mL
pH	Shall not be outside the range 6.0 – 9.0	
Parameter	Average Monthly	Daily Minimum
Total Residual Chlorine	N/A	1.0 mg/L
Dissolved Oxygen Min.	N/A	0.2 mg/L
Parameter	Average Monthly	Seasonal Maximum
Total Nitrogen	N/A	1560 lbs
Total Flow	3.05 million gallons	9.335 million gallons

[a] The average monthly effluent limitation is defined as the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

[b] The highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week. The daily discharge is calculated as the average measurement of the pollutant over the day.

Treated effluent is discharged to Class AA waters of the Wenatchee River during cold weather months. The facility collects and treats wastewater from private residences, a few commercial businesses, public and private campgrounds, and a U.S. Forest Service ranger station located around the eastern end of Lake Wenatchee.

The collection system is a STEP system; primary-level treatment of wastewater occurs in on-site septic tanks and is then conveyed to the main treatment plant through pressurized sewers. During warm weather months, secondary level treatment occurs in a facultative lagoon and an adjacent 11.2 acre sprayfield. Wastewater receives tertiary-level treatment during cold weather months through use of a recirculating sand filter and polishing tank. Tertiary treated effluent is discharged to the Wenatchee River.

The Permittee's record of compliance was excellent for the permit cycle ending 2000. Influent design criteria of the treatment plant were exceeded in 1999 as the collection system was expanded to the state park. The inclusion of the state park took place without the addition of treatment capacity, as specified in 1997 engineering plans. Therefore the current permit requires submittal of a *Plan to Maintain Adequate Capacity* to the Department of Ecology.

Appendix B

2002-03 Sampling of Publicly-Owned Treatment Works, Summary of Field Notes and Influences of Sampling on BOD Results

by Steven Golding

The following is a summary of three sampling events of wastewater plants for the Wenatchee TMDL. The sampling events were conducted July 22-25, August 26-29, and September 23-25, 2002. Dave Holland of Ecology's Central Regional Office assisted in July, Nigel Blakely assisted in August, and Kim Gridley assisted in August.

The Leavenworth POTW, Leavenworth Federal Fish Hatchery (Icicle Creek), Peshastin POTW, and Cashmere POTW were sampled on all three events. In addition, the Lake Wenatchee POTW influent and effluent were grab-sampled in August, as were the Dryden influent and effluent in September.

Leavenworth POTW

The Leavenworth POTW discharges to the river throughout the year. The plant employs UV disinfection. The plant discharges to the river through a single port diffuser at the center of the river.

July 22-25 '02 sampling event

A compositor was set up to take equal volumes of effluent every 30 minutes for 48 hours. A strainer was placed 3 feet upstream of the partial flume, after UV disinfection. No seed was added to the BOD sample and, in concept, the result may have been an artificially low BOD result since the microorganisms needed for a valid BOD test may have been killed by the UV. Lisa Reed of the Leavenworth POTW lab says that they also sample after UV and do not seed the BOD samples because they are concerned that with the plant's low BOD; seed would raise the BOD result artificially.

The Winkler sample for dissolved oxygen was taken just downstream of a one-foot fall, just upstream of the Parshall flume, in non-turbulent effluent.

August 26-29 '02 sampling event

The compositor intake was moved to just before UV so that the sample would contain microorganisms for the BOD test. In this way, no seed was needed, and none was added to the sample. The August result can be considered a valid BOD result for comparison with July's sample, collected and tested in the same way that the Leavenworth POTW plant does. Consider total organic carbon (TOC) and total suspended solids (TSS) during sampling events as an indicator of true plant performance; they should correlate with BOD.

All Winkler and bacteria samples were taken after UV for all three sampling events.

As a result of a communications mix-up, we (Ecology) used TOC filters for orthophosphate samples for all POTWs, August sampling event only. A preliminary result of a later blank we submitted of blank water filtered with a TOC filter and analyzed for orthophosphate showed no contamination, so orthophosphate results for August may be acceptable.

Bill Russ, the plant operator, reported to the Ecology Central Regional Office a spill to the river that took place August 18, 2002. Upon arriving to work at 7:30 AM on August 18, the operator found that a check valve had failed and that a discharge of largely raw influent to the river had been taking place for about three hours. The estimated spill volume was 46,400 gallons, with an estimated 1,250 pounds of solids.

September 23-25 '02 sampling event

The composite sample was collected upstream of UV, and the BOD test was conducted without seed, as in August. A portion of the sample was of UV disinfected wastewater. When Bill Russ told us he had changed his UV flow scheme since August, we moved the compositor to collect most of its sample upstream of UV. Because UV has no residual, as does chlorine disinfection, and because most of sample was before UV, it can safely be assumed there were plenty of microorganisms for a valid BOD test with no need of seed.

April 7-9 '03 sampling event

A compositor was set up in the screening building to collect influent just upstream of screening. The strainer was in only about 4 inches of water so we let the strainer lie on the channel bottom; Flow was turbulent so the sample should be fairly representative. When the scum pump is operating, there is a recirculated stream added upstream of this sampling spot, but the operator reported that the scum pump would not be in operation while Ecology was sampling. BOD testing of the influent sample was requested to be done without seed.

The effluent compositor was set up to sample before (upstream) of UV treatment. The intake was attached to a bamboo pole and placed about 2 feet below the surface. Coliform samples and dissolved oxygen samples were grabbed after UV treatment at the upstream end of the Parshall flume. Because the composite sample was taken before disinfection, effluent BOD testing was requested without seed.

Plant Flows:

8AM July 22 – 8AM July 23 2002: 321,566 gallons per day
8AM Aug 27 – 8AM Aug 28 2002: 356,104 gallons per day
8AM Sept 24 – 8AM Sept 25 2002: 339,864 gallons per day
8AM April 7 – 8 AM April 8 2003: 281,570 gallons per day

Peshastin POTW

The Peshastin POTW, rather than treating wastewater continuously as do most wastewater treatment plants, treats wastewater in batches alternately in two tanks known as sequential batch reactors (SBRs). Peshastin is a small town, and much of the influent comes seasonal from two fruit processors during the packing season that begins in late summer. The SBRs are set to discharge at fixed time intervals (approximately every two hours) when flow does not exceed normal conditions. The SBR tanks are 24 feet in depth, and the top 2 feet is decanted with each cycle. We set our compositors with this fixed time interval so that we would sample only during plant discharge periods. The plant was operating its sampler at shorter fixed intervals so that the sample was being collected when there was no discharge and the effluent was stagnant and warm. I discussed with Dave Johnston, the plant operator, how this leads to invalid samples. We do not know whether this situation was remedied. The plant uses UV disinfection.

July '02 sampling event

The composite sample was collected downstream of UV and, although the microorganisms necessary for a valid BOD may have been killed by the UV, the BOD test was run without seed. As in the Leavenworth POTW sample, the BOD result should be compared with the August and September sampling events (they were sampled in a valid way).

The plant was operating at half capacity, with only one of the SBR tanks, and flow was relatively low since the fruit packers were not yet in the packing season (Dave Johnston said only Bluebird was contributing a small flow of about 2000-3000gpd. He reads their influent flow with a flow meter). The plant operated as expected with fixed timing cycles, and our compositor collected samples during discharge periods as expected.

Because the municipal wastewater contribution to this plant is small and fruit packer wastewater is a major contributor and variable, the plant flow from day-to-day varies more for this plant than most.

August '02 sampling event

The compositor intake was placed before the UV so that the BOD sample would have plenty of microorganisms and not need to be seeded.

All dissolved oxygen and bacteria samples were taken after UV for all three 2002 sampling events.

Because plant flow was higher than expected, the plant was not running on a fixed time cycle and the composite sample could not be used. Dave Johnston said that both Blue Bird and Hi Up (fruit packers) had just started seasonal contributions of wastewater that day. He had not expected Hi Up to be discharging yet. Plant flow records for August show plant flow lower than 40,000 gallons per day from Aug 2-26. August 27, the time we (Ecology) were there, shows a jump in flow to 57,274 gallons. Dave was preparing to begin using the plant's second SBR tank, but it would not be running during our inspection.

The plant was in normal low-flow season operation during our July sampling. In September, it was in normal high-flow season operation. During this August sampling event it was in transition and operating at a higher load than normal. We took a grab sample of effluent during a discharge cycle at 1600 on August 26 to represent effluent during this relatively brief transition period of plant operation. The reason they do not run both SBR tanks year-round is that the microorganisms ("bugs") wouldn't have enough food (organics) to maintain a healthy population.

September '02 sampling event

The plant was operating with both SBR tanks in operation, and the fruit processing plants were discharging to the city's sewer system to the Peshastin POTW. The 49,000 gpd flow during the sampling period was typical of the packing season, but lower than the 57,274 gpd flow of the August sampling period. The composite sample was collected beginning on a Monday. Operator Dave Johnston told us effluent is weaker early in week after fruit packers are closed on weekends. For this reason, we collected an extra sample at 1330 on September 24 (Tuesday) as well.

April '03 sampling event

The plant was still running with both SBRs as it does throughout the fruit processing season. Blue Bird was still doing some fruit packing and contributing some process water to the POTW. The SBR cycle was 2 hr 25 min, with a cycle to begin 1:30 PM on April 8.

The influent was through a pressure line, so I used the facilities compositor for influent, placing our iced base in their open refrigerated sample enclosure. I set up an ISCO sampler to sample every 145 minutes during plant discharge periods, with the intake placed upstream of (before) UV.

Plant flows:

8AM July 23 – 8AM July 24 2002: 37,950 gallons per day
8AM Aug 26 – 8AM Aug 27 2002: 57,274 gallons per day
8AM Sept 23 – 8AM Sept 24 2002: 49,000 gallons per day
8AM April 8 – 8 AM April 9 2002: 32,590 gallons per day

Self reporting by the Peshastin POTW shows the following flows for July-Oct '02:

Avg. (MGD)	Max. (MGD)	
July	0.035	0.057
August	0.036	0.059
September	0.045	0.058
October	0.051	0.064

Cashmere POTW

The Cashmere POTW is a 3-lagoon system. The plant chlorinates and dechlorinates with SO_2. The city samples before chlorination. This may inflate BOD results. We (Ecology) set up the compositor at the outlet of the last lagoon, also before chlorination, for all three sampling events. It should be noted that the SO_2 added downstream of our sampling location exerts an additional oxygen demand not included in the sample. This also provides a sample with microorganisms that does not require seed. Dissolved oxygen and bacteria samples were collected after chlorination and dechlorination for all three 2002 sampling events. The city dredged cell #1 the day before the July sampling. This would create a tendency toward lower quality effluent with more solids and associated organics, but Tom Hastings, operator, said he didn't think it would have any effect. The plant has a seasonal algae problem and high pH, so plant personnel add HCl to the effluent as needed. During the September sampling event, Tom Hastings said they hadn't added any acid since the end of July (they only do so when pH >9). We measured a pH of 8.09 during the September 2002 sampling event, and Tom said they measured about 8.1.

April '03 sampling event

As in previous sampling events, the downstream half of the final pond was covered with black plastic to reduce algal growth and corresponding rises in pH. The pH was running about 8.5 according to operator Tom Hastings. He said they were not adding acid yet for the season, as they will be later in the summer to bring down effluent pH as a result of algal pH increases. The water in the first pond looked green as it was sprayed by the aerator. The TOC effluent sample looks green as compared with the DOC clear sample.

The city samples influent as two separate flows, separately from the city and the Treetop Bulk Volume Fermenter (BVF). Since this was impractical to do, I collected grab samples from the influent box where the two influents come in from separate pipes and mix.

The effluent compositor intake was submerged in the effluent box from the final pond, as in all previous sampling events. As before, dissolved oxygen and coliform samples were taken after disinfection, at the outfall of the chlorination basin, just upstream of a one-foot drop into a vertical outflow pipe.

The plant operator, Tom Hastings, reports effluent BODs in the range of 20 to 30 mg/L.

Flows:

7:30 AM July 24 – 7:30 AM July 25 2002: 0.3424 MGD
7:30 AM Aug 26 – 7:30 AM Aug 27 2002: 0.3955 MGD
7:30 AM Sept 23 – 7:30 AM Sept 24 2002: 0.300 MGD
7:30 AM April 7 – 7:30 AM April 8 2003: 0.4420 MGD

Leavenworth Federal Fish Hatchery (Icicle Creek)

Main discharge at Parshall flume to river

Two discharges were sampled at the fish hatchery. The main discharge to the river was sampled in the Parshall flume after the flows from the hatchery were commingled and well-mixed, just before the discharge reached the river. The second discharge was of the settling pond discharge, sometimes referred to by the sampler as "clean" discharge as the pond settled the cleaning water from tank cleaning.

During all three 2002 sampling events, the Parshall flume was flowing freely so it could be used for valid measurements. We measured the vertical distance from the water surface at the location in the flume where an ultrasonic detector had been located (a PVC pipe is still there) as this is the location where flow is determined from Parshall flumes. This vertical distance was 205 cm at 1405 on July 23; and 200 cm at 1110 and 208 cm at 1445 on August 27. This lowest flow in August of the three sampling events corresponded with the concrete apron across the river just upstream of the discharge point being dry for the only time during the three sampling events. These vertical measured distances can be used to calculate flows if the Parshall flume width and vertical distance from the top of grate to bottom of flume are known.

The sampling point for the grab samples at the Parshall flume was at the upstream end of the flume in July, and it is possible that the two nearby process water streams were not yet well mixed. This was remedied in the August and September sampling when the sampling point was moved to the downstream end of the flume, with considerable turbulence upstream of the sampling point for thorough mixing.

Settling pond (abatement pond) discharge

Dan Davies of the hatchery provided the following schedule for August cleaning of the 8-ft x 80-ft tanks and the 10-ft x 100-ft tanks. He indicates that no chlorine or any other disinfectant is used in the tank cleaning process.

August 2002

19, Monday	upper 8x80s and lower 10x100s
20, Tuesday	mid 8x80s
21, Wednesday	mid 8x80s and upper 10x100s
22, Thursday	lower 8x80s
23, Friday	upper 8x80s and lower 10x100s
24, Saturday	mid 8x80s
25, Sunday	upper 10x100s
26, Monday	lower 8x80s and lower 10x100s
27, Tuesday	upper 8x80s
28, Wednesday	mid 8x80s and upper 10x100s
29, Thursday	lower 8x80s

During cleaning, the 10-ft x 100-ft tanks are drawn down from a depth of four feet to one foot. The 8-ft x 80-ft tanks are drawn down from 2 ½ feet to one foot.

In July a grab sample from the settling pond was collected when we came upon it discharging at 1100 on July 22. Tank cleaning takes place in the morning, and the Ecology flow meter showed that most of the pond discharge takes place at that time of day.

We met Ecology co-worker, Dustin Bilhimer, at the cleaning pond on August 28 to read the data-logger for stage. From the data log, we were able to see that there is a high discharge in morning when the tanks are cleaned, with flow tapering off rapidly thereafter. Based on this, we planned to sample the next day, making a flow-weighted grab composite by hand.

On August 29, 2002, we grabbed samples every 15 minutes between 0615 and 0930, keeping each sample separate in the bottles of a sequential compositor. Then we flow weighted the samples based on the ISCO flow book charts for approximate flow rate for a 3.75 foot wide weir with end contractions. The maximum flow rate during that period was found to be approximately 6.9 cfs. The total flow volume during the sampling period was calculated to be approximately 17,700 cu ft. If the average baseflow was about 0.3 cfs, an estimate, the unsampled 20.75 hr portion of that day's flow was approximately 22,400 cu ft, the estimated total flow per 24-hour period being 30,100 cu ft.

Because the August 29 sampling represented a lower than maximum volume of cleaning water, we sampled during a day when a maximum amount of cleaning water was discharged. I sampled on the morning of Wednesday, September 25, 2002. The depth of flow over the weir was high, noticeably higher than during the August sampling. The maximum flow was estimated to be 7.8 cfs, and the total discharge during the 8:00 AM – 10:00 AM sampling period was approximately 42,700 cu ft, more than double the volume sampled during the August sampling. If baseflow is assumed again to be 0.3 cfs, the flow was 225,200 gallons per day.

Summary estimated flows for Hatchery abatement pond

August 29, 2002:	30,100 cu ft (24-hour period)
September 25, 2002:	66,460 cu ft (24-hour period)

More precise measurements of flows in the hatchery abatement pond may be determined from the continuous flow recording devices Ecology placed in operation during the 2002-03 survey period.

Dryden Treatment System

The small community of Dryden treats its wastewater in a community septic system. The system is operated by Dave Johnson, who also operates the Peshastin plant. Dave says that the groundwater problems in the area may be, at least in part, a result of the irrigation a few hundred feet uphill from a fruit packing house. Dave Holland of Ecology's Central Regional Office says that there have been two sampling wells to monitor the effects of the system but that Ecology asked the PUD not to sample any longer since the results were not helpful.

The Dryden septic system consists of three drainfields, two being used during any single year. The two chambers being used have an automatic switch to cause their use to be alternated. Dave told us he has had problems with uneven flow and irregular filling between the two tanks. Influent and effluent samples were collected from manholes on September 23, 2002

Lake Wenatchee POTW

The Lake Wenatchee POTW was sampled on August 26, 2002. Discharge to land is permitted from April 1 through September 30. During the winter, a filter is used to improve effluent quality to tertiary standards for discharge to Class AA waters of the Wenatchee River. The plant was applying effluent to a sprayfield during the August 2002 sampling, and less restrictive limitations applied than during the April 2003 sampling when discharge was to the river. We sampled from the influent and effluent vaults during the August 2002 sampling.

The POTW was sampled again in April 2003 when a recirculating sand filter was being operated for tertiary treatment. I grab-sampled from a pressurized influent line and collected a 24-hour composite sample from the effluent box, just before effluent is released through a culvert to the river. (I did not sample before chlorination because there is a settling basin after the accessible non-chlorinated point). The operator said the effluent was chlorinated to 0.03 mg/L, but not dechlorinated.

Appendix C

Data Results for Publicly-Owned Treatment Works

by Steven Golding

The following is a summary of results from data for the wastewater treatment systems sampled. Data include results from effluent sampled in July, August, and September 2002, as well as influent and effluent sampled in April 2003.

Quality Assurance/Quality Control

The following tables (C1 – C11) show lab duplicate and field replicate results. Pairs of results and lab duplicates for all parameters have a relative percent difference (RPD) of less than 7%, except for chloride at 11% and fecal coliform at 58%. Field replicate results for all parameters had RPDs of less than 15%, except for total suspended solids (TSS) and dissolved organic carbon (DOC). TSS had values of 2 and 3 mg/L, showing good agreement despite the high RPD at these low values. DOC had a RPD of 28%, indicating possible contamination of the field-filtered sample during filtering.

Leavenworth POTW

The plant performed very well throughout the survey. Effluent BOD_5 was nondetectable except for one value of 1.1 mg/L in April 2003. The composite effluent sample had been collected before UV disinfection. This compares with a permit limit of 30 mg/L BOD_5. The maximum effluent TSS during the survey was 4 mg/L compared to the permit limit of 30 mg/L. BOD_5 removal was found to be 99.5% during the April 2003 sampling event, compared with a permit requirement of 85% removal. TSS removal was 98.9%, compared to a required 85%.

Effluent TOC values were close in value throughout the survey, another indication of uniform plant operation for the dates sampled.

Effluent ammonia (NH_3)–N was less than 0.2 mg/L throughout the survey, compared to a permit limit of 15.5 mg/L. This indicates that near-complete nitrification was taking place, with a removal efficiency of 100.0%. Nitrite-nitrate (NO_2-NO_3) values were correspondingly elevated to above 7 mg/L throughout the survey, as ammonia was converted to nitrites and then nitrates. Alkalinity was substantially used in the nitrification process in the August 2002 sampling event and, although it was not a factor during the survey, there is the potential for alkalinity to become limiting to nitrification, and the meeting of ammonia permit limits.

Fecal coliform counts were well within permit limits for the dates sampled.

Field measurements of pH showed all values within the permit limit of 6.0 – 9.0.

In July we sampled after UV disinfection and did not add seed for the BOD test. This is the protocol the POTW uses for its monitoring. It is possible that this can cause an artificially low BOD result since UV can kill the microorganisms that are necessary for biochemical oxidation in the BOD test. In July and August we sampled upstream of UV and added no seed. The POTW continued to sample downstream of UV and add no seed. The following analysis is to test the hypothesis that sampling downstream of UV without adding seed suppresses the biochemical reactions in the BOD test, causing an under-reporting of BOD during the first (July) sampling event.

	BOD_5	TSS	TOC (all mg/L, all composite samples)
July	2U	3	4.7
Aug	2U	4	5.8
Sept	2U	2	4.9

With the effluent of similar quality with respect to TSS and TOC (an indicator of organic content), the BOD_5 tests showed the same nondetect result. The effect of sampling downstream of UV and not adding seed when BOD is within the detectable range is not known. The possibility should be considered that during periods of less effective plant operation than were observed during this survey, the plant under-reports effluent BOD.

Peshastin POTW

The plant performed well during the survey. Because of the variable nature of the fruit processing influent and the small size of the plant, the operator had to make adjustments, but effluent quality remained good.

Effluent BOD_5 was 4 mg/L and 6 mg/L (est.) compared to a permit limit of 30 mg/L. BOD_5 removal was determined in April 2003 and found to be 98.8%, compared to a permit limit of 90%. Effluent TSS ranged from not detectable at a detection limit of 1 mg/L to 4 mg/L. TSS removal was calculated at 84.2% in April 2003, slightly under the permit requirement of 85%. This was a result of the unusually low influent TSS concentration of 19 mg/L, presumably due to the nature of fruit industry process water.

Nitrification was near complete during the survey, with effluent NH_3 concentrations consistently below 0.2 mg/L, meeting permit limits of 10 mg/L. NO_2-NO_3 concentrations were correspondingly high, above 12 mg/L except for values below 3 mg/L in July 2002. Ammonia removal was 100.0% in April. Alkalinity was not close to limiting nitrification.

Fecal coliform permit limits were met, with most values below detection limits.

All effluent pH values determined in the field were within permit limits.

Cashmere POTW

The plant performed well during the survey. Effluent BOD_5 ranged from 16 – 22 mg/L during the survey, compared to a permit limit of 45 mg/L. BOD_5 removal efficiency calculated from

April 2003 data was 82.2%, meeting the permit limit of 65%. Effluent TSS values ranged from 6 – 20 mg/L, meeting the permit limit of 75 mg/L. TSS removal efficiency was calculated at 84.4% in April 2003.

Nitrification (oxidation of ammonia) was largely incomplete. Effluent NH_3 concentrations ranged from 1.42 – 8.38 mg/L. NO_2-NO_3 effluent concentrations were all below 0.8 mg/L except for one anomalous value of 4.95 mg/L. The finding in April 2003 of effluent ammonia concentrations of approximately 8 mg/L compared to an influent concentration of 12.4 mg/L, as well as the relatively high NH_3 concentrations throughout the survey, suggest that low NO_2-NO_3 effluent concentrations cannot be explained to be a result of denitrification in anoxic conditions, as might be suspected. Substantial alkalinity was present to provide for potential denitrification. This is further supported by alkalinity declining only slightly between influent and effluent in April. As the plant was functioning, with little nitrification occurring, effluent NH_3 concentrations provided an oxygen demand for the receiving water.

Effluent fecal coliform counts ranged from 14 – 170 (est.)/100 mL, meeting the permit limit of 200/100 mL monthly and 400/100 mL weekly.

Field measurements of effluent pH were within limits during the survey.

Lake Wenatchee POTW

The plant performed well during the survey. Effluent BOD_5 was found to be 5 and 1.3 mg/L during the survey, compared to seasonal permit limits of 10 mg/L total BOD_5 and 20 mg/L soluble BOD_5, respectively. BOD_5 removal efficiency calculated from April 2003 data was 98.8%. BOD_5 removal was also efficient during the sprayfield discharge season in August 2002. Effluent TSS values were 50 mg/L in August, compared to a permit limit of 67.5 mg/L average weekly for the sprayfield season. The effluent TSS value in April was 1 mg/L, compared to a permit limit of 10 mg/L daily. TSS removal efficiency was calculated at 90.0% in April 2003. Effluent TSS was higher in August than was influent TSS.

Nitrification was essentially complete both in August and April, with NO_2-NO_3 concentrations of 27.5 (est.) and 22.2 mg/L and NH_3 concentrations of 0.128 and 0.122 mg/L for those two months, respectively. These ammonia concentrations are well below the permit limit for discharge to the river of 7 mg/L average monthly. Ammonia removal efficiency in April was 99.5 %. Sufficient alkalinity remained in the effluent so as not to constrain nitrification, with effluent alkalinity dipping to 31 mg/L (est.) only in August, a level that suggests alkalinity be watched by the plant operator.

The fecal coliform count met permit limits, as did the pH measured in the field.

Plant flow in August, during the sprayfield season, was reported to be 0.0388 MGD. This is within the average monthly permitted flow of 0.05 MGD for that season.

Dryden POTW

The Dryden plant is a septic tank system. Influent and effluent can be sampled only from large concrete tanks with quiescent, sluggish flow, placing doubt on the representativeness of the samples. The effluent actually leaving the drainfields near the river could not be measured.

BOD_5 discharged to the drainfields was found to be 118 mg/L for a single measurement in September 2002, meeting the permit limit of 230 mg/L daily maximum. TSS was 23 mg/L, meeting the permit limit of 150 mg/L. pH was within permit limits.

Self-reported flow data for the period of the survey indicate that the permitted daily maximum flow limit of 0.023 MGD was not exceeded. (Flow is recorded only weekly but represent flows less than the limit).

Ammonia discharged to the drainfield had a concentration of 25.8 mg/L.

Federal Fish Hatchery at Icicle Creek – Main Outfall

As shown in the data table, BOD_5 and TSS concentrations in the fish hatchery main outfall discharge were below detection limits of 2 mg/L and 1 mg/L respectively. An exception was a TSS concentration of 2 mg/L from a grab sample collected on June 25, 2002. Effluent NH_3 concentrations ranged from 0.026 to 0.095 mg/L. While both NH_3 and NO_2-NO_3 were found in low concentrations relative to those of the municipal POTWs in the survey, the finding of NH_3 and NO_2-NO_3 in approximately equal concentrations indicates only partial or no nitrification of ammonia to nitrate was taking place in the facility. Because inflow to the hatchery was not sampled, data indicating changes in nutrients and alkalinity across the hatchery are not available to provide confirmation of this. Effluent alkalinity was more than adequate to allow for complete nitrification of the ammonia concentrations found in the effluent. The finding of only partial nitrification is not surprising since treatment is not provided for flow-through water.

Federal Fish Hatchery at Icicle Creek – Abatement Pond Effluent

The abatement pond settles solids from daily cleaning of fish-holding tanks. The flow from the abatement pond spikes during the few hours after cleaning during weekday mornings. BOD_5 concentrations were not detectable throughout the survey at a detection limit of 2 mg/L. An indication of organic concentration is TOC and DOC, ranging from 1.1 – 1.6 mg/L throughout the survey. DOC tended to be approximately 0.1 mg/L lower than TOC, indicating that the organics in the effluent were substantially in dissolved form.

TSS ranged from 2 – 6 mg/L during the survey. NO_2-NO_3 as nitrogen ranged from nondetect at 0.01 mg/L to 0.139 mg/L. NH_3 as nitrogen ranged from 0.05 – 0.071 mg/L. For most sampling dates, NH_3 concentrations were higher than NO_2-NO_3, indicating little or no nitrification of the pond effluent was taking place. Alkalinity was not limiting to nitrification. Phosphorus results were erratic in June and July, 2002, with two points higher than 49 mg/L. Other phosphorus results for the abatement pond discharge during the survey were 0.103 mg/L or lower.

Peshastin POTW

The Peshastin POTW, like the Leavenworth POTW, was sampled downstream of UV in July and upstream in September. Both tests were run without seed:

	BOD_5	TSS	TOC	(all mg/L, composite samples)
July	4	1U	7.0	
Sept	6J	4	12.7	

The results show that when the effluent was disinfected with UV and the BOD test was conducted without seed in July, a biochemical reaction took place yielding a BOD (4 mg/L). The September test results were in line with the July results. The somewhat higher BOD_5 result in September is consistent with the somewhat stronger effluent as indicated by TSS and TOC. Although there are insufficient data for definite conclusions, it appears that sampling downstream of UV (as in August) provides enough live microorganisms in the sample for valid results without seeding. Any future sampling for the TMDL should continue to be upstream of UV disinfection, to ensure the validity of results, however.

Table C-1. Peshastin POTW Data, 2002-03.

Date:	7/23-24/02	7/24/02	8/26/02	9/23-24/02	9/24/02	4/7-8/03	4/7-8/03			July-Sept	July-April		
Type of sample:	Effluent grab	Effluent comp	Effluent grab	Effluent grab	Effluent comp	Effluent grab	Effluent comp	Influent comp	Efficiency % Removal	Mean	Mean	Stnd Dev	90th percentile
BOD5 (mg/L)		4		6 J	6 J			135		5.00	5.00	1.41	6.81
BODU (mg/L)													
TSS (mg/L)	1 U 1 U	1 U	4 4	2 3 5	4	1 3	3	19	84.2	2.50	2.67	1.53	4.62
TDS (mg/L)	399 394	394	580 632	1030 846	1030	472 466	470	430	-9.3	712.00	631.33	347.34	1076.48
TNVSS (mg/L)	1 U 1 U	1 U											
TOC (mg/L)	7.5 7.5	7.9	8.5 9	11.6 11.5 11.9	12.7	11.6 10.9	9.1	65.4	86.1	10.30	9.90	2.50	13.10
DOC (mg/L)	7.6 7.1	8	7.9 8.6	11 10.1	11.4	9.4 10	8.9	45.8	80.6	9.70	9.43	1.76	11.69
TPN (mg/L)	3.17 3.61	2.96	19.9 18.6	15.9 17.3	14.9	13.7 16.4	18.2	33.3	45.3	8.93	12.02	8.02	22.30
Phosphorus (mg/L)	3.69 3.53	3.5	7.19 6.84	7.99 J 7.77 J	7.97	7.41 6.92	7.05	5.5	-28.2	5.74	6.17	2.36	9.20
Ortho-P (mg/L)	4.52 3.83	3.3	7.47 7	7.34 7.14	7.44	7.66 6.94	7.06	5.3	-33.2	5.37	5.93	2.29	8.87
NO2-NO3 (mg/L)	2.15 2.82	2.07	19.8 J 17.8 J	16.1 1.72	15.1	12.8 14.8	16	0.033	-48384.8	8.59	11.06	7.80	21.05
NH3 (mg/L)	0.226 0.067	0.171	0.038 0.522	0.01 U 0.019	0.016	0.016 0.015	0.015	31.6	100.0	0.09	0.07	0.09	0.18
Chloride (mg/L)	37.9 37		45.2 41.1	68.5 J 56.9 J	68.5 J	57.9 53.7	54.6	41.7	-30.9	68.50	61.55	9.83	74.15
Alkalinity (mg/L)	217 214	218	168 175	186 182	190	179 174	170	351	51.6	204.00	192.67	24.11	223.57
E.Coli (#/100mL)	1 U		1 U	1 UJ		3 U 1 U							
Fecal Coli (#/100mL)	1 U		1 U	3 J		3 U							

- The September 23, 2001 NO2-NO3 value of 1.72 mg/L is an apparent outlier.
- apparent outlier
*TSS removal efficiency misleading since inf TSS is low

Table C-2. Leavenworth WWTP Data, 2002-03

Date:	7/22/02	7/23/02	8/27-28/02	8/28/02	9/24-25/02	9/25/02	4/7/03	4/7/03	4/7-8/03	Efficiency	July-Sept	July-April		
Type of sample:	Effluent grab	Effluent comp	Effluent grab	Effluent comp	Effluent grab	Effluent comp	Effluent grab	Effluent comp	Influent comp	% Removal	Mean	Mean	Stnd Dev	90th Percentile
BOD5 (mg/L)		2 U		2 U		2 U		1.1	219	99.5	2	1.775	0.45	2.35
BODU (mg/L)														
TSS (mg/L)	4 3	3	3 3	4	1 U 2	2	6 1 U 3	2	174	98.9	3	2.75	0.96	3.98
TDS (mg/L)	206 201	200	224 212	216	184 186	186	189 192 191	192	224	14.3	200.7	198.5	13.00	215.16
TNVSS (mg/L)	NAF NAF	1 U												
TOC (mg/L)	4.3 4.5	4.7	5.8 5.1	5.8	4.7 5.1	4.9	4.6 4.8 5.2	5.2	84.2	93.8	5.1	5.15	0.48	5.76
DOC (mg/L)	4.7 4.5	5.4	5.7 5.2	5.4	4.3 4.5	4.3	4.8 4.8 4.9	4.7	63.2	92.6	5.0	4.95	0.54	5.65
TPN (mg/L)	12.6 12.1	12.1	15.7 17.6	16.8	10.9 11.3	10.9	9.9 9.94 9.09	10.5	28.6	63.3	13.3	12.58	2.90	16.29
Phosphorus (mg/L)	2.78 2.93	3.03	5.74 6.07	6.04	1.71 2.36	2.21	2.14 1.97 2.31	2.26	4.89	53.8	3.8	3.385	1.81	5.70
Ortho-P (mg/L)	3.41 J 3.21 J	3.62	5.63 6.03	6.02	1.55 1.98	1.71	2.17 2.1 2.39	2.41	3.7	34.9	3.8	3.44	1.89	5.87
NO2-NO3 (mg/L)	11.5 11.8	11.5	15.7 J 17.3 J	16.6 J	10.6 1.19	1.16	8.58 7.91 8.61	8.93	0.264	-3282.6	9.8	9.548	6.44	17.80
NH3 (mg/L)	0.051 0.031	0.05	0.086 0.055	0.074	0.045 0.034	0.036	0.015 0.011 0.011	0.012	25.6	100.0	0.1	0.043	0.03	0.08
Chloride (mg/L)	28.8 30.3	30.5	28.7 27.9	29	26.6 J 29.5	29	27.8 27.6 27.1	27.5	28.4	3.2	29.5	29	1.22	30.57
Alkalinity (mg/L)	25 26	26	10 J 6	9	34 32	33	45 44 44	45	158	71.5	22.7	28.25	15.04	47.53
E.Coli (#100/mL)	3		8		1		9							
Fecal Coli (#/100mL)	3		31 J		1		3							

* The NO2-NO3 values of 1.19 and 1.16 mg/L for 09/24-25/02 are apparent outliers.

Table C-3. Lake Wenatchee WWTP Data, 2002-03

Date:	8/26/02		4/9/03		4/8-9/03		
Type of sample:	Effluent grab	Influent grab	Effluent grab	Effluent grab	Effluent comp	Influent grab	Efficiency % Removal
BOD5 (mg/L)	5	112			1.3	106	98.8
BODU (mg/L)							
TSS (mg/L)	50	14	1	1 U	1	10	90.0
TDS (mg/L)	472	344	327	331	326	245	-33.1
TNVSS (mg/L)							
TOC (mg/L)	15.8	64.9 J	4.6	4.7	5.7	42.3	86.5
DOC (mg/L)	13.6	38.1	3.9	3.9	3.8	34.4	89.0
TPN (mg/L)	29.1	69.7	23.5	24.8	26	29.1	10.7
Phosphorus (mg/L)	7.15	9	2.81	2.85	2.85	4.12	30.8
Ortho-P (mg/L)	6.53	8.77	2.93	2.9	2.93	4.16	29.6
NO2-NO3 (mg/L)	27.5 J	0.026 J	22.9	23.5	22.2	0.019	-116742.1
NH3 (mg/L)	0.128	69	0.1	0.091	0.122	24	99.5
Chloride (mg/L)	114	61.8	33.2	32.2	34.7	24.9	-39.4
Alkalinity (mg/L)	31 J	366 J	75.6	75.2	70.9	206	65.6
E.Coli (#/100mL)	3 U			14			
Fecal Coli (#/100mL)	3 U			26			

Table C-4. Dryden WWTP Data, 2002-03

Date:	9/23/02				
Type of sample:	Effluent grab		Influent grab		Efficiency % Removal
BOD5 (mg/L)	118		709		83.4
BODU (mg/L)					
TSS (mg/L)	23		131		82.4
TDS (mg/L)	328		403		18.6
TNVSS (mg/L)					
TOC (mg/L)	57.8		106		45.5
DOC (mg/L)	33.6		65.5		48.7
TPN (mg/L)	31.1		38.6		19.4
Phosphorus (mg/L)	4.17	J	4.08	J	-2.2
Ortho-P (mg/L)	3.26		1.44		-126.4
NO2-NO3 (mg/L)	0.01	U	0.564		98.2
NH3 (mg/L)	25.8		11.1		-132.4
Chloride (mg/L)	24.1J		16.9	J	-47.9
Alkalinity (mg/L)	297		228		-30.3
E.Coli (#/100mL)	NC				
Fecal Coli (#/100mL)	NC				

Table C-5. Cashmere WWTP Data, 2002-03

Date:	7/24/02	7/25/02	8/26/02	8/27/02	9/23/02	9/24/02	4/7-8/03	4/7-8/03			July-Sept	July-April		
Type of sample:	Effluent grab	Effluent comp	Effluent grab	Effluent comp	Effluent grab	Effluent comp	Effluent grabs	Effluent comp	Influent grab	Efficiency % Removal	Mean	Mean	Stnd Dev	90th percentile
BOD5 (mg/L)		16		22		22 J		16.1	91	100.0	20	19.025	3.44	23.43
BODU (mg/L)														
TSS (mg/L)	20 16	20	6 15	6	12 14	11	17 16 16	14	90	84.4	12.33	12.75	5.85	20.25
TDS (mg/L)	694 682	685	770 770	737	742 741	742	626 622 617	632	613	-3.1	721.33	699.00	51.57	765.09
TNVSS (mg/L)	2 2	2												
TOC (mg/L)	13.3 12.8	13.8	13.5 12.4	13.3	17.5 16.8	17.3	16.4 16.6 16.6	16.1	43.4	62.9	14.80	15.13	1.89	17.55
DOC (mg/L)	12.6 12.4	12.3	12.0 11.9	12.3	15.6 15	15.9	11 10.8 11.3	15	32.4	53.7	13.50	13.88	1.86	16.25
TPN (mg/L)	3.9 3.93	4.03	3.97 3.98	4.13	3.98 3.98	3.89	11.3 11.5 10.3	9.87	13.7	28.0	4.02	5.48	2.93	9.23
Phosphorus (mg/L)	4.12 4.13	4.19	5.23 5.32	5.33	5.65 J 5.5 J	5.44	2.29 2.29 2.33	2.33	2.17	-7.4	4.99	4.32	1.44	6.17
Ortho-P (mg/L)	3.82 4	3.93	5.22 5.18	5.1	5.36 5.48	5.51	2.3 2.15 2.35	2.51	1.59	-57.9	4.85	4.26	1.35	5.99
NO2-NO3 (mg/L)	0.01 U 0.014	0.01 U	0.01 UJ 0.01 J	0.01 J	0.52 4.95	0.55	0.766 0.753 0.755	0.75	0.196	-284.2	0.19	0.33	0.38	0.82
NH3 (mg/L)	1.57 1.91	1.86	1.64 1.56	1.66	1.35 1.42	1.68	7.45 7.57 7.56	8.38	12.4	32.4	1.73	3.40	3.32	7.66
Chloride (mg/L)			70.9 71.1	71.9	69.5 J 69 J	68.6 J	46.5 46.6 47	46.8	42.9	-9.1	70.25	62.43	13.64	79.91
Alkalinity (mg/L)	521 515	516	587 586 J	591 J	559 558	560	530 521 522	527	544	3.1	555.67	548.50	33.95	592.01
E.Coli (#/100mL)	110		74		57 J		3							
Fecal Coli (#/100mL)	170 J		86 J		120 J		14							

Table C-6. Leavenworth Fish Hatchery Abatement Pond Outfall Data, 2002-03

Date:	6/25/02	7/22/02	7/23/02	8/29/02	9/25/02	10/22/02	4/8/03
Type of sample:	grab	grab	grab	grab-comp	grab-comp	grab	grab
BOD5 (mg/L)		2 U		2 U	2 U		
BODU (mg/L)							
TSS (mg/L)	2	4	2	2	2	3 3	6
Turbidity (NTU)	1.7		0.9			1 0.9	2.7
TDS (mg/L)	27	30	32	38	39		
TNVSS (mg/L)	2	NAF	1				
TOC (mg/L)	1.6	1.1	1.1	1.3	1.2	1.2	1.4
DOC (mg/L)		1.1		1.1	1 U	1.3	1.3
TPN (mg/L)	0.126	0.088	0.126	0.194	0.206	0.045 0.063	0.304
Phosphorus (mg/L)	0.0497	0.042	53.7	0.103	0.073	0.029 0.029	
Ortho-P (mg/L)	0.028	0.017 J	0.027	0.0665	0.042	0.013 0.012	0.0396
NO2-NO3 (mg/L)	0.01 U	0.01 U	0.01 U	0.029 J	0.082	0.016 0.016	0.139
NH3 (mg/L)	0.05	0.037	0.058	0.056	0.071	0.013 0.015	0.056
Chloride (mg/L)	0.22		0.21	0.46	0.67 J	0.62 0.62	1.99
Chlorophyll (ug/L)							5.8
Alkalinity (mg/L)	13	16	16	25	29	34 33	40
E.Coli (#/100mL)						1 UJ 1 UJ	1 U
Fecal Coli (#/100mL)						1 UJ 2 J	1 U

Table C-7. Leavenworth Fish Hatchery Main Outfall Data, 2002-03

Date:	6/25/02	7/23/02	7/22-23/02	8/27/02	8/28/02	9/24/02	9/25/02	10/22/02	4/8/03
Type of Sample:	grab	grab	comp	grab	grab	grab	grab	grab	grab
BOD5 (mg/L)			2 U				2 U		
BODU (mg/L)									
TSS (mg/L)	2	1 U	1 U	1	1 U	1 U	1 U	1 U	1 U
		1 U							1 U
Turbidity (NTU)	1.1							0.5 U	0.5 U
									0.5 U
TDS (mg/L)	28	27	28	30	36	50	51		
		26							
TNVSS (mg/L)	1	1 U	1 U						
		1 U							
TOC (mg/L)	1.2	1 U	1.4	1	1 U	1.1	1 U		1.2
		1.1							1.4
DOC (mg/L)		1.1	1.3	1.8	1	1 U	1.1		1.3
		1							1.3
TPN (mg/L)	0.10	0.144	0.135	0.105	0.105	0.214	0.224	0.025 U	0.21
		0.155							0.21
Phosphorus (mg/L)	0.014	0.011	0.013	0.015	0.006	0.024	0.016	0.0065	0.015
		0.011							0.014
Ortho-P (mg/L)	0.008	0.0071	0.012	0.013	0.007	0.013	0.014	0.0069	0.012
		0.0089							0.012
NO2-NO3 (mg/L)	0.01 U	0.013	0.011	0.022 J	0.026 J	0.152	0.157	0.018	0.084
		0.013							0.083
NH3 (mg/L)	0.039	0.095	0.072	0.039	0.058	0.041	0.051	0.026	0.057
		0.091							0.055
Chloride (mg/L)	0.24	0.3	0.31	0.38	0.41	0.91 J	1.91	0.64	1.12
		0.24							1.14
Chlorophyll (ug/L)									0.47
									0.43
Alkalinity (mg/L)		17	16	24 J	24	34	35	34	30
		16							31
E.Coli (#/100mL)		1		1		1 U			
Fecal Coli (#/100mL)		1 U		2		1 U			

- September data points are apparent outliers. NO2-NO3 data for other facilities in September 2002 were also anomalous.

Table C-8. 2002-2003 Wenatchee River TMDL Point Source Effluent Flow Rates

Source of Data	Period of Record	Flow (MGD)	Flow (cfs)
Leavenworth Wastewater Treatment Plant			
Reported design flow	NA	0.84	1.30
Average daily measurement	7/22-23/02	0.32	0.50
	8/27-28/02	0.36	0.55
	9/24-25/02	0.34	0.53
	4/8-9/03	0.28	0.44
Reported from DMR	2003-2004	0.32 - 0.43	0.50 - 0.67
Peshastin Wastewater Treatment Plant			
Reported design flow	NA	0.11	0.17017
Average daily measurement	7/23-24/02	0.04	0.06
	(7/22-23/02)	0.05	0.07
	(7/21-22/02)	0.03	0.04
	8/26-27/02	0.06	0.09
	9/23-24/02	0.05	0.08
	4/8-9/03	0.03	0.05
Reported from DMR	Sept-Nov 03-04	0.045 - 0.061	0.07 - 0.09
	Dec-Aug 03-04	0.03 - 0.046	0.05 - 0.07
Cashmere Wastewater Treatment Plant			
Reported design flow	NA	0.94	1.45
Average daily measurement	7/24-25	0.34	0.53
	8/26-27	0.40	0.61
	9/23-24	0.30	0.46
	4/8-9	0.44	0.68
Reported from DMR	Oct-Nov 02	0.66	1.02
	May-Jul 02	0.50	0.77
Lake Wenatchee Wastewater Treatment Plant			
Reported design flow	NA	0.046	0.07
Average daily measurement	8/26-27/02	0.04	0.06
	4/8-9/03	0.01	0.02
Reported from DMR	Sep-Apr 03-04	0.014 - 0.030	0.02 - 0.05

DMR – Discharge monitoring report

Table C-8 (cont).

Source of Data	Period of Record	Flow (MGD)	Flow (cfs)
Dryden Wastewater Treatment Plant			
No flows are available for the day of sampling.			
Monthly flows (note that permit is as daily maximum flow)			
Reported design flow	NA	0.02	0.03

DMR – Discharge monitoring report

Table C-9. Wenatchee TMDL Point Source Effluent QA/QC Data - Results and Lab Duplicate Results

WWTP Facility:	Leavenworth			Peshastin			Cashmere			Lake Wen.			Dryden			Leave Hatchery Main Outfall			Leave Hatchery Abat. Pond		
	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD
BOD5 (mg/L)				6 J	6 J	0.0	22	22	0	5	5	0	118	105	11.7	2 U	2 U	0	2 U	2 U	0
							16	16	0	5	5	0				2 U	2 U	0			
							24	24	0												
BODU (mg/L)																					
TSS (mg/L)				5	5	0.0															
Turbidity (NTU)																					
TDS (mg/L)	184	184	0.0													30	28	6.9			
	212	215	1.4																		
TNVSS (mg/L)																					
TOC (mg/L)	5.1	5.3		11.6	11.9	2.6	17.3	17.1	1.16							1.4	1.4	0			
							13.3	13.1	1.52												
DOC (mg/L)							12.0	12.1	0.83												
							12.6	13.2	4.65												
TPN (mg/L)							3.98	4.14	3.94							0.105	0.099	5.9			
Phosphorus (mg/L)				7.19	7.05	2.0															
Ortho-P (mg/L)				7.47	7.19	3.8															
				3.3	3.39	2.7															
NO2-NO3 (mg/L)							0.014	0.015	6.9												

Dupe - duplicate

RPD - relative percent difference, the difference between two values divided by their mean expressed as a percentage.

Table C-9 (cont.)

																	Leave Hatchery					
WWTP Facility:	Leavenworth			Peshastin			Cashmere			Lake Wen.			Dryden			Main Outfall			Abat. Pond		
	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD	Samp	Dupe	RPD
NH3 (mg/L)				0.010 U 0.067	0.010 U 0.066	0 1.504															
Chloride (mg/L)																0.3	0.27	11			
Chlorophyll (ug/L)																					
Alkalinity (mg/L)				168	168	0										17	16	6.1	25	25	
E.Coli (#/100mL)				1 U	1 U	0															
Fecal Coliform (#/100mL)	1	2		1 U	1 U	0	120 J	66 J	58.1												

Dupe - duplicate

RPD - relative percent difference, the difference between two values divided by their mean expressed as a percentage.

Table C-10. Wenatchee TMDL Point Source Effluent QA/QC Data - Comparison of Results and Field Replicates

													Leave Hatchery			
WWTP Facility:	Leavenworth			Peshastin		Cashmere			Lake Wen.		Dryden		Main Outfall		Abat. Pond	
Date:	4/7/03					4/7/03										
Sample type:	samp	rep	RPD	samp	rep	samp	rep	RPD	samp	rep	samp	rep	samp	rep	samp	rep
BOD5 (mg/L)																
BODU (mg/L)																
TSS (mg/L)	2	3	40.0			14	16	13.3								
Turbidity (NTU)																
TDS (mg/L)	192	191	0.5			632	617	2.4								
TNVSS (mg/L)																
TOC (mg/L)	5.2	5.2	0.0			16.1	16.6	3.1								
DOC (mg/L)	4.7	4.9	4.2			15	11.3	28.1								
TPN (mg/L)	10.5	9.09	14.4			9.87	10.3	4.3								
Phosphorus (mg/L)	2.26	2.31	2.2			2.33	2.33	0.0								
Ortho-P (mg/L)	2.41	2.39	0.8			2.51	2.35	6.6								

RPD - relative percent difference, the difference between two values divided by their mean expressed as a percentage.

Table C-10 (cont.)

													Leave Hatchery			
WWTP Facility:	Leavenworth			Peshastin		Cashmere			Lake Wen.		Dryden		Main Outfall		Abat. Pond	
Date:	4/7/03					4/7/03										
Sample type:	samp	rep	RPD	samp	rep	samp	rep	RPD	samp	rep	samp	rep	samp	rep	samp	rep
NO2-NO3 (mg/L)	8.93	8.61	3.6			0.753	0.759 0.755	0.8 0.3								
NH3 (mg/L)	0.012	0.011	8.7			8.38	7.56	10.3								
Chloride (mg/L)	27.5	27.1	1.5			46.8	47	0.4								
Chlorophyll (ug/L)																
Alkalinity (mg/L)	45	44	2.2			527	522	1.0								
E.Coli (#/100mL)																
Fecal Coliform (#/100mL)																

RPD - relative percent difference, the difference between two values divided by their mean expressed as a percentage.

Table C-11. Water quality characteristics of contact cooling water discharge to the Wenatchee River.

Facility Name	Permit	M-PT	Qual2k km	Dmr Date or Sample Date	Flow gpd	Contained additives?	Chloride (as CL) mg/L	pH	TSS mg/L	Temp. Water (° C)	BOD, 5-DAY (20° C) mg/L	Conductivity umhos	Alkalinity mg/L	Diss. Oxy mg/L	Ortho-P ug/L	TP ug/L	NH4 ug/L	NO23 ug/L	TPN ug/L	TOC mg/L	TON ug/L	TOP ug/L
Blue Bird Peshastin Plant	WAG435090B	796A		1-Jul-02	2280	N	4.6	8.26	2.3	15	<5											
		796A	54.8	**1-Oct-02**	**2280**	**N**	**5.6**	**7**	**1**	**15**	**<5**											
		796A		1-Jan-03	96000	N	6.5	7.7	10	17	<5											
		796A		1-Apr-03	96000	N	11.7	6.83	<1	18	<5											
		796A		1-Jul-03	96000	N	6.3	8.02	<1	19	<5											
		796A		1-Oct-03	96000	N	3.5	7.58	<1	18	<5											
		796B		1-Jul-02	34560	N	2.2	8.05	2	16	<5											
		796B	54.7	**1-Oct-02**	**34560**	**N**	**4.9**	**8.27**	**<1**	**18**	**<5**											
		796B		1-Jan-03	500	Y	3.7	8.27	<1	14	<5											
		796B		1-Apr-03	500	Y	4.6	8.01	<1	14	<5											
		796B		1-Jul-03	500	Y	13.1	8.68	7	18	<5											
		796B		1-Oct-03	500	Y	11.8	8.38	8	16	<5											
		796C		1-Jul-02	17280	N	4.3	7.64	8	18	<5											
		796C	54.8	**1-Oct-02**	**17280**	**N**	**5.7**	**8.3**	**<1**	**19**	**<5**											
		796C		1-Jan-03	1000	Y	12.8	8.48	4.5	12	<5											
		796C		2-Jan-03	30000	N	7	8.26	1	16	<5											
		796C		1-Apr-03	1000	Y	9.8	8.66	4	18	<5											
		796C		2-Apr-03	30000	N	6.5	8.35	1.5	18	<5											
		796C		1-Jul-03	1000	Y	12.7	8.62	7.5	19	<5											
		796C		2-Jul-03	30000	N	11.2	8.54	5.5	19	<5											
		796C		1-Oct-03	1000	Y	3.8	7.98	5	19	<5											
		796C		2-Oct-03	30000	N	3.8	7.98	5	20	<5											
		796D		1-Jul-02	17280	N	3.2	8.29	2.5	19	<5											
		796D	54.8	**1-Oct-02**	**17280**	**N**	**6.2**	**8.16**	**1**	**18**	**<5**											
		796D		1-Jan-03	17280	N	6.7	8.19	1	19	5											
		796D		1-Apr-03	17280	N	6.1	8.28	2	14	5											
		796D		1-Jul-03	17280	N	6.5	8.2	2	16	5											
		796D		1-Oct-03	17280	N	3.2	8.01	1	18	5											
		796E		1-Jul-02	30000	N	4.3	7.85	5.5	20	<5											
		796E	54.9	**1-Oct-02**	**30000**	**N**	**13.8**	**8.35**	**3**	**20**	**5.4**											
		796E		1-Jan-03	20000	N	12.2	8.32	1.5	12	14.2											
		796E		1-Apr-03	20000	N	8	8.02	204	11	<5											
		796E		1-Jul-03	20000	N	16.4	8.42	8.5	12	<5											
		796E		1-Oct-03	20000	N		8.52	1	11	<5											
Bardin Farms Corp Packing Plant	WAG435094B	786A		1-Jul-02	3300	Y	9.8	8.72	<1		<5											
		786A	78.1	**1-Oct-02**	**2985**	**Y**	**12.1**	**8.83**	**<1**	**15.8**	**<5**											
		786A		1-Apr-03	2000	Y	10.6	8.77	2		<5											
		786B		1-Jul-02	1900	Y	11.2	8.9	<1		<5											
		786B	78.1	**1-Oct-02**	**3722**	**Y**	**9.8**	**8.57**	**<1**	**17.6**	**<5**											
		786B		1-Apr-03	none																	
Blue Star Growers Cashmere	WAG435140B	8	72.9	**20-Dec-04**	**2700**	**Y**	**16.5**	**8.39**		5.95		**755.6**	**365**	**11.77**	**139**	**240**	**75**	**7490**	**7700**	**2.8**	**135**	**101**
Blue Bird Peshastin Plant	WAG435090B	796A	54.8	20-Dec-04	96000	N	4.65	7.95		11.76		**309.9**	**152**	**10.15**	**40.7**	**37.2**	**30**	**3305**	**3450**	<1	**115**	**-3.5**
		796B		20-Dec-04	not measured	Y	12.1	8.77		16.61		700.8	340	9.3	189	2380	<10	11500	12900	4.8	1395	2191
		796C	54.8	20-Dec-04	not measured	N	5.13	7.8		16.66		**350.4**	**167**	**7.48**	**45.6**	**40.9**	**<10**	**3810**	**3800**	<1	**-15**	**-4.7**
		796D	54.8	20-Dec-04	10000	N	4.58	7.95		11.76		**309.9**	**150**	**10.15**	**40.5**	**38.3**	**82**	**3280**	**3600**	<1	**238**	**-2.2**
		796E	54.9	20-Dec-04	not measured	N	4.68	7.82		10.64		**320.9**	**152**	**10.08**	**41.7**	**40.6**	**11**	**3330**	**3500**	<1	**159**	**-1.1**
Bardin Farms Corp Packing Plant	WAG435094B	786A	78.1	21-Dec-04	not measured	Y	11.5	8.93		15.44		**963.4**	**365**	**10.17**	**175**	**2920**	**<10**	**10400**	**12300**	**4.8**	**1895**	**2745**
		786B	78.1	21-Dec-04	not measured	Y	12.3	8.53		18.85		**1068**	**249**	**9.64**	**150**	**3300**	**<10**	**10400**	**11700**	**5.2**	**1295**	**3150**

M-PT - Monitoring point
Dmr - Discharge monitoring report
Bold - Data were used in the model

Appendix D

Wenatchee River and Icicle Creek
QUAL2K Model Calibration Coefficients and Reach Characteristics

Table D-1. Rate parameters used for Wenatchee River QUAL2K model (page 1).

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	0.5	gA	gA
Inorganic suspended solids:			
Settling velocity	1.07896	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal		
Temp correction	1.024		θ_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.6349	/d	k_{hc}
Temp correction	1.047		θ_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		θ_{dcs}
Fast CBOD:			
Oxidation rate	1.818	/d	k_{dc}
Temp correction	1.047		θ_{dc}
Organic N:			
Hydrolysis	3.8998	/d	k_{hn}
Temp correction	1.07		θ_{hn}
Settling velocity	0.86972	m/d	v_{on}
Ammonium:			
Nitrification	4.6736	/d	k_{na}
Temp correction	1.07		θ_{na}
Nitrate:			
Denitrification	0.05976	/d	k_{dn}
Temp correction	1.07		θ_{dn}
Sed denitrification transfer coeff	0.03291	m/d	v_{di}
Temp correction	1.07		θ_{di}
Organic P:			
Hydrolysis	4.21255	/d	k_{hp}
Temp correction	1.07		θ_{hp}
Settling velocity	1.27552	m/d	v_{op}
Inorganic P:			
Settling velocity	0.31988	m/d	v_{ip}
Sed P oxygen attenuation half sat constant	1.6811	mgO_2/L	k_{spi}

Table D-1 (continued). Rate parameters used for Wenatchee River QUAL2K model (page 2).

Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		θ_{gp}
Respiration rate	0.1	/d	k_{rp}
Temp correction	1.07		θ_{rp}
Death rate	0	/d	k_{dp}
Temp correction	1.07		θ_{dp}
Nitrogen half sat constant	15	ugN/L	k_{sPp}
Phosphorus half sat constant	2	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Phytoplankton use HCO3- as substrate	Yes		
Light model	Half saturation		
Light constant	57.6	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.15	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	350	mgA/m^2/d or /d	C_{gb}
Temp correction	1.075		θ_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.391128	/d	k_{rb}
Temp correction	1.028133		θ_{rb}
Excretion rate	0.203688	/d	k_{eb}
Temp correction	1.0132804		θ_{db}
Death rate	0.014374	/d	k_{db}
Temp correction	1.0513975		θ_{db}
External nitrogen half sat constant	493.223	ugN/L	k_{sPb}
External phosphorus half sat constant	52.79	ugP/L	k_{sNb}
Inorganic carbon half sat constant	2.56E-05	moles/L	k_{sCb}
Bottom algae use HCO3- as substrate	Yes		
Light model	Half saturation		
Light constant	70.75045	langleys/d	K_{Lb}
Ammonia preference	1.2	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	4.82859864	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.8668423	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	ρ_{mN}
Maximum uptake rate for phosphorus	10	mgP/mgA/d	ρ_{mP}
Internal nitrogen half sat ratio	1.08438		$K_{qN,ratio}$
Internal phosphorus half sat ratio	1.330476		$K_{qP,ratio}$
Detritus (POM):			
Dissolution rate	2.63515	/d	k_{dt}
Temp correction	1.07		θ_{dt}
Settling velocity	1.0098	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		θ_{dx}
Settling velocity	1	m/d	v_x
alpha constant for light mortality	1	/d per ly/hr	*apath*
pH:			
Partial pressure of carbon dioxide	375	ppm	p_{CO2}

Table D-2. Rate parameters used for Icicle Creek QUAL2K model (page 1).

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	0.5	gA	gA
Inorganic suspended solids:			
Settling velocity	0.60832	m/d	v_i
Oxygen:			
Reaeration model	USGS(channel-control)		
Temp correction	1.024		θ_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	1.6233	/d	k_{hc}
Temp correction	1.047		θ_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		θ_{dcs}
Fast CBOD:			
Oxidation rate	0.5712	/d	k_{dc}
Temp correction	1.047		θ_{dc}
Organic N:			
Hydrolysis	0.1	/d	k_{hn}
Temp correction	1.07		θ_{hn}
Settling velocity	0.5	m/d	v_{on}
Ammonium:			
Nitrification	10	/d	k_{na}
Temp correction	1.07		θ_{na}
Nitrate:			
Denitrification	0.66408	/d	k_{dn}
Temp correction	1.07		θ_{dn}
Sed denitrification transfer coeff	0.31461	m/d	v_{di}
Temp correction	1.07		θ_{di}
Organic P:			
Hydrolysis	0.1	/d	k_{hp}
Temp correction	1.07		θ_{hp}
Settling velocity	0.5	m/d	v_{op}
Inorganic P:			
Settling velocity	0.921	m/d	v_{ip}
Sed P oxygen attenuation half sat constant	1.40408	mgO_2/L	k_{spi}

Table D-2 (continued). Rate parameters used for Icicle Creek QUAL2K model (page 2).

Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		θ_{gp}
Respiration rate	0.1	/d	k_{rp}
Temp correction	1.07		θ_{rp}
Death rate	0	/d	k_{dp}
Temp correction	1.07		θ_{dp}
Nitrogen half sat constant	15	ugN/L	k_{sPp}
Phosphorus half sat constant	2	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Phytoplankton use HCO3- as substrate	Yes		
Light model	Half saturation		
Light constant	57.6	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.15	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	142	mgA/m²/d or /d	C_{gb}
Temp correction	1.08		θ_{gb}
First-order model carrying capacity	1000	mgA/m²	$a_{b,max}$
Respiration rate	0.37026	/d	k_{rb}
Temp correction	1		θ_{rb}
Excretion rate	0.268964	/d	k_{eb}
Temp correction	1		θ_{db}
Death rate	0.001	/d	k_{db}
Temp correction	1.07		θ_{db}
External nitrogen half sat constant	425.381	ugN/L	k_{sPb}
External phosphorus half sat constant	61.065	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Bottom algae use HCO3- as substrate	Yes		
Light model	Half saturation		
Light constant	57.27853	langleys/d	K_{Lb}
Ammonia preference	15	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	4.2647544	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.6	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	ρ_{mN}
Maximum uptake rate for phosphorus	10	mgP/mgA/d	ρ_{mP}
Internal nitrogen half sat ratio	1.3303635		$K_{qN,ratio}$
Internal phosphorus half sat ratio	1.397346		$K_{qP,ratio}$
Detritus (POM):			
Dissolution rate	2.53045	/d	k_{dt}
Temp correction	1.07		θ_{dt}
Settling velocity	0.2532	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		θ_{dx}
Settling velocity	1	m/d	v_x
alpha constant for light mortality	1	/d per ly/hr	*apath*
pH:			
Partial pressure of carbon dioxide	375	ppm	p_{CO2}

Table D-3. Reach level data for the Wenatchee River QUAL2K model.

Downstream end of reach label	Number	Reach length (km)	Downstream Latitude	Downstream Longitude	Downstream location (km)	Elevation Upstream (m)	Elevation Downstream (m)	Rating Curves Velocity Coefficient	Rating Curves Velocity Exponent	Rating Curves Depth Coefficient	Rating Curves Depth Exponent	Channel Slope
lake wenatchee	0		48.00	121.00	0.000		569.000	0.0800	0.590	0.3319	0.300	0.0016
	1	1.00	48.00	121.00	1.000	569.000	567.600	0.0800	0.590	0.3319	0.300	0.0014
	2	1.00	48.00	121.00	2.000	567.600	566.500	0.1100	0.540	0.2594	0.370	0.0011
	3	1.00	48.00	121.00	3.000	566.500	565.700	0.1100	0.540	0.3763	0.290	0.0008
	4	1.00	48.00	121.00	4.000	565.700	564.700	0.0800	0.590	0.3786	0.310	0.001
	5	1.00	48.00	121.00	5.000	564.700	564.000	0.1100	0.540	0.2461	0.390	0.0007
	6	1.00	48.00	121.00	6.000	564.000	563.200	0.1100	0.540	0.1973	0.400	0.0008
	7	1.00	48.00	121.00	7.000	563.200	562.200	0.1400	0.490	0.1620	0.440	0.001
	8	1.00	48.00	121.00	8.000	562.200	561.500	0.0400	0.640	0.5948	0.290	0.0007
	9	1.00	48.00	121.00	9.000	561.500	560.500	0.2300	0.330	0.1008	0.610	0.001
	10	1.00	48.00	121.00	10.000	560.500	557.900	0.1700	0.440	0.1386	0.490	0.0026
	11	1.00	48.00	121.00	11.000	557.900	555.400	0.1100	0.540	0.1874	0.410	0.0025
plain	12	1.00	48.00	121.00	12.000	555.400	552.900	0.1100	0.540	0.1417	0.420	0.0025
	13	1.00	48.00	121.00	13.000	552.900	550.400	0.1100	0.540	0.1856	0.410	0.0025
	14	1.00	48.00	121.00	14.000	550.400	547.700	0.1100	0.540	0.2030	0.400	0.0027
	15	1.00	48.00	121.00	15.000	547.700	547.700	0.1100	0.540	0.1853	0.410	0.0027
	16	1.00	48.00	121.00	16.000	547.700	547.700	0.1100	0.540	0.2226	0.390	0.0025
	17	1.00	48.00	121.00	17.000	547.700	545.200	0.1100	0.540	0.1825	0.420	0.0025
	18	1.00	48.00	121.00	18.000	545.200	544.500	0.1100	0.540	0.2454	0.350	0.0007
railroad bridge	19	1.00	48.00	121.00	19.000	544.500	535.800	0.2300	0.330	0.1082	0.560	0.0087
	20	1.00	48.00	121.00	20.000	535.800	531.700	0.2300	0.330	0.0786	0.600	0.0041
	21	1.00	48.00	121.00	21.000	531.700	527.800	0.2300	0.330	0.1360	0.510	0.0039
	22	1.00	48.00	121.00	22.000	527.800	524.900	0.2300	0.330	0.1742	0.480	0.0029
	23	1.00	48.00	121.00	23.000	524.900	522.400	0.2300	0.330	0.1391	0.520	0.0025
	24	1.00	48.00	121.00	24.000	522.400	520.200	0.2300	0.330	0.2121	0.460	0.0022
	25	1.00	48.00	121.00	25.000	520.200	517.700	0.1400	0.490	0.2563	0.320	0.0025
	26	1.00	48.00	121.00	26.000	517.700	515.600	0.2300	0.330	0.0625	0.630	0.0021
	27	1.00	48.00	121.00	27.000	515.600	513.200	0.1400	0.490	0.1209	0.460	0.0024
	28	1.00	48.00	121.00	28.000	513.200	510.300	0.1400	0.490	0.3256	0.300	0.0029
tumwater	29	1.00	48.00	121.00	29.000	510.300	506.900	0.1400	0.490	0.1291	0.470	0.0034
	30	1.00	48.00	121.00	30.000	506.900	503.600	0.2300	0.330	0.1242	0.540	0.0033
	31	1.00	48.00	121.00	31.000	503.600	500.300	0.2300	0.330	0.1542	0.580	0.0033
	32	1.00	48.00	121.00	32.000	500.300	495.800	0.2300	0.330	0.1400	0.580	0.00450
	33	1.00	48.00	121.00	33.000	495.800	491.000	0.2300	0.330	0.1384	0.580	0.00480
	34	1.00	48.00	121.00	34.000	491.000	483.500	0.2300	0.330	0.1353	0.560	0.00750
	35	1.00	48.00	121.00	35.000	483.500	469.200	0.0400	0.710	0.9270	0.150	0.01430
	36	1.00	48.00	121.00	36.000	469.200	459.200	0.2300	0.330	0.1513	0.570	0.01000
jolanda	37	1.00	48.00	121.00	37.000	459.200	454.500	0.0500	0.330	0.2707	0.620	0.00470
	38	1.00	48.00	121.00	38.000	454.500	432.300	0.1400	0.330	0.1600	0.560	0.02220
	39	1.00	48.00	121.00	39.000	432.300	418.100	0.1400	0.520	0.1946	0.370	0.01420
	40	1.00	48.00	121.00	40.000	418.100	406.800	0.1400	0.520	0.2151	0.400	0.01130
	41	1.00	48.00	121.00	41.000	406.800	395.700	0.2300	0.330	0.1764	0.560	0.01110
	42	1.00	48.00	121.00	42.000	395.700	379.100	0.1400	0.520	0.1897	0.420	0.01660
	43	1.00	48.00	121.00	43.000	379.100	356.300	0.1400	0.520	0.2130	0.330	0.02280
abv leavenworth	44	1.00	48.00	121.00	44.000	356.300	341.800	0.2300	0.330	0.2406	0.540	0.01450
	45	1.00	48.00	121.00	45.000	341.800	335.200	0.1400	0.520	0.2420	0.370	0.00660
	46	1.00	48.00	121.00	46.000	335.200	333.200	0.0400	0.710	0.5221	0.170	0.00200
	47	1.00	48.00	121.00	47.000	333.200	332.000	0.1400	0.520	0.1662	0.340	0.00120
	48	1.00	48.00	121.00	48.000	332.000	330.200	0.0400	0.710	0.4576	0.210	0.00180
	49	1.00	48.00	121.00	49.000	330.200	327.300	0.2300	0.330	0.2001	0.540	0.00290
	50	1.00	48.00	121.00	50.000	327.300	327.300	0.140	0.490	0.150	0.450	0.00290
	51	1.00	48.00	121.00	51.000	327.300	327.300	0.040	0.640	0.815	0.250	0.01070
peshastin	52	1.00	48.00	121.00	52.000	327.300	316.600	0.040	0.640	0.608	0.290	0.01070
	53	1.00	48.00	121.00	53.000	316.600	314.000	0.040	0.640	0.597	0.310	0.00260
	54	1.00	48.00	121.00	54.000	314.000	311.300	0.140	0.490	0.131	0.470	0.00270
	55	1.00	48.00	121.00	55.000	311.300	308.700	0.230	0.330	0.094	0.620	0.00260
	56	1.00	48.00	121.00	56.000	308.700	306.100	0.230	0.330	0.075	0.630	0.00260
	57	1.00	48.00	121.00	57.000	306.100	302.700	0.170	0.430	0.097	0.530	0.00340
dryden	58	1.00	48.00	121.00	58.000	302.700	298.500	0.110	0.520	0.235	0.370	0.00420
	59	1.00	48.00	121.00	59.000	298.500	294.200	0.110	0.520	0.207	0.400	0.00430
	60	1.00	48.00	121.00	60.000	294.200	289.200	0.110	0.520	0.163	0.420	0.00500
	61	1.00	48.00	121.00	61.000	289.200	283.800	0.110	0.520	0.228	0.400	0.00540
	62	1.00	48.00	121.00	62.000	283.800	278.500	0.110	0.520	0.242	0.390	0.00530
blw dryden	63	1.00	48.00	121.00	63.000	278.500	272.600	0.110	0.520	0.164	0.420	0.00590
	64	1.00	48.00	121.00	64.000	272.600	266.800	0.110	0.520	0.220	0.380	0.00580
	65	1.00	48.00	121.00	65.000	266.800	261.100	0.110	0.520	0.281	0.360	0.00570
	66	1.00	48.00	121.00	66.000	261.100	255.800	0.110	0.520	0.224	0.380	0.00530
	67	1.00	48.00	121.00	67.000	255.800	252.100	0.110	0.520	0.225	0.370	0.00370
	68	1.00	48.00	121.00	68.000	252.100	247.600	0.110	0.520	0.154	0.440	0.00450
above cashmere	69	1.00	48.00	120.00	69.000	247.600	243.600	0.100	0.560	0.223	0.360	0.00400
	70	1.00	48.00	120.00	70.000	243.600	240.600	0.100	0.560	0.196	0.410	0.00300
	71	1.00	48.00	120.00	71.000	240.600	238.600	0.100	0.560	0.326	0.260	0.00200
	72	1.00	48.00	120.00	72.000	238.600	234.800	0.100	0.560	0.370	0.240	0.00380
	73	1.00	48.00	120.00	73.000	234.800	230.600	0.100	0.560	0.232	0.340	0.00420
	74	1.00	48.00	120.00	74.000	230.600	230.500	0.100	0.560	0.179	0.410	0.00010
	75	1.00	48.00	120.00	75.000	230.500	227.300	0.070	0.600	0.301	0.330	0.00320
monitor	76	1.00	48.00	120.00	76.000	227.300	216.800	0.070	0.600	0.258	0.350	0.01050
	77	1.00	47.00	120.00	77.000	216.800	212.500	0.100	0.560	0.172	0.400	0.00430
	78	1.00	47.00	120.00	78.000	212.500	208.300	0.100	0.560	0.219	0.350	0.00420
	79	1.00	47.00	120.00	79.000	208.300	206.000	0.100	0.560	0.225	0.350	0.00230
	80	1.00	47.00	120.00	80.000	206.000	204.000	0.100	0.560	0.292	0.270	0.00200
sleepy hollow	81	1.00	47.00	120.00	81.000	204.000	201.400	0.100	0.560	0.233	0.310	0.00260
	82	1.00	47.00	120.00	82.000	201.400	198.900	0.100	0.560	0.210	0.340	0.00250
	83	1.00	47.00	120.00	83.000	198.900	197.900	0.100	0.560	0.228	0.340	0.00100
	84	1.00	47.00	120.00	84.000	197.900	193.700	0.100	0.560	0.173	0.400	0.00420
	85	1.00	47.00	120.00	85.000	193.700	191.100	0.100	0.560	0.210	0.380	0.00260
mouth	86	1.00	47.00	120.00	86.000	191.100	184.600	0.100	0.560	0.175	0.360	0.00650

Table D-4. Reach level data for the Icicle Creek QUAL2K model.

Downstream end of reach label	Number	Reach length (km)	Downstream Latitude	Downstream Longitude	Downstream location (km)	Elevation Upstream (m)	Elevation Downstream (m)	Rating Curves Velocity Coefficient	Rating Curves Velocity Exponent	Rating Curves Width Coefficient	Rating Curves Width Exponent	Channel Slope
	0		47.61	120.91	0.000		831.600	0.1300	0.380	17.7700	0.241	0.014
	1	0.50	47.61	120.91	0.500	831.600	826.000	0.1300	0.380	17.7700	0.241	0.014
	2	0.50	47.61	120.90	1.000	826.000	817.700	0.1300	0.380	17.7700	0.241	0.0166
	3	0.50	47.61	120.90	1.500	817.700	812.200	0.1300	0.380	17.7700	0.241	0.0164
	4	0.50	47.61	120.89	2.000	812.200	807.400	0.1300	0.380	17.7700	0.241	0.0096
	5	0.50	47.61	120.89	2.500	807.400	800.700	0.1300	0.380	17.7700	0.241	0.0172
	6	0.50	47.61	120.88	3.000	800.700	792.200	0.1300	0.380	17.7700	0.241	0.017
	7	0.50	47.61	120.88	3.500	792.200	785.100	0.1300	0.380	17.7700	0.241	0.017
	8	0.50	47.61	120.87	4.000	785.100	778.600	0.1300	0.380	17.7700	0.241	0.0132
	9	0.50	47.61	120.86	4.500	778.600	775.200	0.1300	0.380	17.7700	0.241	0.0068
	10	0.50	47.61	120.86	5.000	775.200	772.200	0.1300	0.380	17.7700	0.241	0.006
	11	0.50	47.61	120.85	5.500	772.200	768.700	0.1300	0.380	17.7700	0.241	0.007
	12	0.50	47.61	120.84	6.000	768.700	764.500	0.1300	0.380	17.7700	0.241	0.0084
	13	0.50	47.61	120.84	6.500	764.500	760.400	0.2500	0.370	18.5100	0.187	0.0098
	14	0.50	47.61	120.83	7.000	760.400	756.400	0.2500	0.370	18.5100	0.187	0.008
	15	0.50	47.60	120.83	7.500	756.400	748.400	0.2500	0.370	18.5100	0.187	0.016
	16	0.50	47.60	120.82	8.000	748.400	739.700	0.2500	0.370	18.5100	0.187	0.0174
	17	0.50	47.60	120.82	8.500	739.700	731.400	0.2500	0.370	18.5100	0.187	0.0166
	18	0.50	47.60	120.82	9.000	731.400	724.900	0.2500	0.370	18.5100	0.187	0.013
	19	0.50	47.59	120.81	9.500	724.900	717.600	0.2500	0.370	18.5100	0.187	0.0146
	20	0.50	47.59	120.81	10.000	717.600	708.700	0.2500	0.370	18.5100	0.187	0.0178
	21	0.50	47.59	120.81	10.500	708.700	703.600	0.2500	0.370	18.5100	0.187	0.0142
	22	0.50	47.58	120.80	11.000	703.600	690.000	0.1300	0.380	17.7700	0.241	0.0272
	23	0.50	47.58	120.80	11.500	690.000	673.700	0.1300	0.380	17.7700	0.241	0.0326
	24	0.50	47.58	120.79	12.000	673.700	658.100	0.1300	0.380	17.7700	0.241	0.0312
	25	0.50	47.57	120.79	12.500	658.100	639.000	0.1300	0.380	17.7700	0.241	0.0382
	26	0.50	47.57	120.79	13.000	639.000	631.100	0.1300	0.380	17.7700	0.241	0.0158
	27	0.50	47.57	120.78	13.500	631.100	626.500	0.1300	0.380	17.7700	0.241	0.0092
xsection MP 9.9	28	0.50	47.56	120.78	14.000	626.500	622.700	0.2500	0.370	18.5100	0.187	0.0076
	29	0.50	47.56	120.78	14.500	622.700	600.100	0.1300	0.380	17.7700	0.241	0.0452
	30	0.50	47.56	120.77	15.000	600.100	584.700	0.1300	0.380	17.7700	0.241	0.0308
xsection MP 9.1	31	0.50	47.55	120.77	15.500	584.700	571.000	0.1300	0.380	17.7700	0.241	0.0274
	32	0.50	47.55	120.77	16.000	571.000	560.500	0.1300	0.380	17.7700	0.241	0.02100
xsection MP 8.5	33	0.50	47.55	120.76	16.500	560.500	553.700	0.1300	0.380	17.7700	0.241	0.01360
	34	0.50	47.55	120.75	17.000	553.700	540.900	0.1300	0.380	17.7700	0.241	0.02560
xsection MP 7.8	35	0.50	47.55	120.75	17.500	540.900	522.900	0.1300	0.380	17.7700	0.241	0.04120
	36	0.50	47.54	120.74	18.000	522.900	505.700	0.1300	0.380	17.7700	0.241	0.03440
	37	0.50	47.54	120.74	18.500	505.700	495.800	0.1300	0.380	17.7700	0.241	0.01980
xsection MP 6.9	38	0.50	47.54	120.73	19.000	495.800	480.600	0.1300	0.380	17.7700	0.241	0.03040
	39	0.50	47.54	120.73	19.500	480.600	459.300	0.1300	0.380	17.7700	0.241	0.04260
	40	0.50	47.54	120.72	20.000	459.300	434.600	0.1300	0.380	17.7700	0.241	0.04940
	41	0.50	47.54	120.71	20.500	434.600	420.500	0.1300	0.380	17.7700	0.241	0.02820
Icicle Irrigation withdrawal	42	0.50	47.54	120.71	21.000	420.500	393.300	0.1300	0.380	17.7700	0.241	0.05440
	43	0.50	47.55	120.70	21.500	393.300	377.000	0.1300	0.380	17.7700	0.241	0.03260
	44	0.50	47.55	120.70	22.000	377.000	365.600	0.1300	0.380	17.7700	0.241	0.02280
xsection MP 4.9	45	0.50	47.55	120.69	22.500	365.600	356.000	0.1300	0.380	17.7700	0.241	0.01920
	46	0.50	47.55	120.68	23.000	356.000	351.100	0.1300	0.380	17.7700	0.241	0.00980
xsection MP 4.1	47	0.50	47.55	120.68	23.500	351.100	347.800	0.1300	0.380	17.7700	0.241	0.00660
old channel-headgate	48	0.50	47.55	120.67	24.000	347.800	344.500	0.3200	0.320	7.9900	0.067	0.00660
old channel	49	0.50	47.55	120.67	24.500	344.500	341.300	0.6000	0.030	8.2000	0.601	0.00640
old channel	50	0.50	47.56	120.67	25.000	341.300	340.600	0.600	0.030	8.200	0.601	0.00200
old channel-mouth	51	0.50	47.56	120.67	25.500	340.600	340.000	0.430	0.700	8.860	0.164	0.00140
	52	0.50	47.56	120.67	26.000	340.000	339.300	0.070	0.610	21.930	0.153	0.00160
	53	0.50	47.57	120.67	26.500	339.300	338.300	0.070	0.610	21.930	0.153	0.00200
	54	0.50	47.57	120.66	27.000	338.300	337.600	0.070	0.610	21.930	0.153	0.00180
	55	0.50	47.57	120.66	27.500	337.600	336.800	0.070	0.610	21.930	0.153	0.00160
	56	0.50	47.57	120.66	28.000	336.800	336.100	0.070	0.610	21.930	0.153	0.00340
	57	0.50	47.57	120.66	28.500	336.100	335.300	0.050	0.680	25.960	0.056	0.00220
	58	0.50	47.57	120.66	29.000	335.300	334.700	0.090	0.700	24.970	0.129	0.00160
	59	0.50	47.58	120.66	29.500	334.700	334.200	0.090	0.700	24.970	0.129	0.00140
	60	0.50	47.58	120.66	30.000	334.200	333.500	0.090	0.700	24.970	0.129	0.00140

Appendix E

Groundwater Statistics by Designated Subbasin

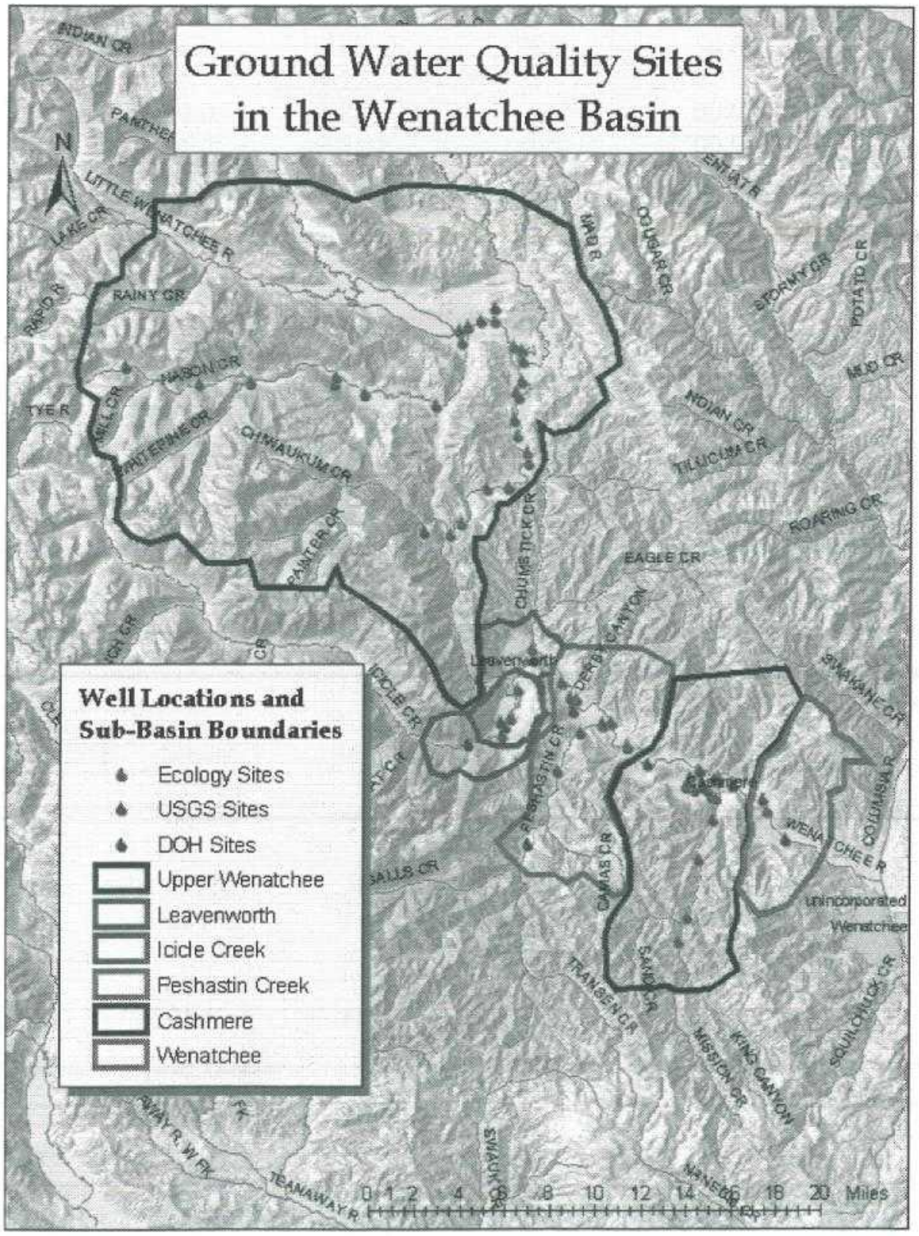

Figure E-1. Map of well locations and designated subbasin boundaries used for groundwater water quality characteristics and statistics (see Table E-1).

Table E-1. Groundwater water quality statistics by designated subbasin (see Figure E-1).

Upper Wenatchee

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	45.00	0.67	76	0.06	0.0115
90th percentile	82.00	3.03	153	0.27	0.027
95% UTI	119.08	4.80	212	0.43	0.0427
mean	45.40	1.26	83	0.11	0.01387
standard deviation	28.87	1.38	55	0.12	0.0099
number	15	15	22	14	10
minimum	10.00	0.20	28	0.01	0.005
maximum	109.00	4.62	217	0.42	0.0382

Leavenworth

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	45.5	0.85	72	0.4655	0.0135
90th percentile	110.01	9.92	225.1	1.04	0.029
95% UTI	211.16	20.25	318.82	1.89	0.054
mean	56.6667	2.9563	112.6818	0.4746	0.0173
standard deviation	41.6253	5.4085	87.7151	0.4440	0.0098
number	6	8	22	8	6.00
minimum	22	0.23	22	0.03	0.01
maximum	134	16.1	330	1.19	0.0349

Icicle Creek

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	34	0.85	63	0.422	0.011
90th percentile	65.9	11.4	118.72	1.09	0.02
95% UTI	122.37	26.63	176.29	2.1	0.056
mean	41.2000	3.3633	76.9444	0.4674	0.0138
standard deviation	19.2795	6.2651	40.4991	0.4763	0.0052
number	5	6	18	7	5
minimum	22	0.3	22	0.03	0.01
maximum	66	16.1	184	1.19	0.022

Peshastin Creek

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	120	5.03	128	3.49	0.150
90th percentile	202.5	7.6	433.85	7.55	0.510
95% UTI	286.45	11.7	558.81	10.5	0.906
mean	124.5385	4.0725	225.6792	3.9499	0.1896
standard deviation	60.4712	2.8148	162.1845	2.8133	0.2465
number	13	12	53	23	10
minimum	35	0.68	43	0.01	0.006
maximum	264	7.43	634	9.6099997	0.841

Table E-1 (continued). Groundwater water quality statistics by designated subbasin (see Figure E-1).

Cashmere

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	206	4.240	383	5.23	0.017
90th percentile	285.81	5.860	542.98	11.11	0.021
95% UTI	376.01	7.900	638.68	14.04	0.027
mean	202.5385	3.9823	381.6909	6.3809	0.0170
standard deviation	64.9662	1.4708	125.6087	3.6904	0.0028
number	13	13	55	39	7
minimum	10	2.100	161	0.53	0.014
maximum	280	7.400	671	12.2	0.021

Wenatchee

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	275	7.2	180.5	7.1700001	
90th percentile	537.81	14.9	843.06	10.18	
95% UTI				13.91	
mean	275.0000	7.2000	328.2500	7.0691	
standard deviation	205.0610	6.0811	401.8908	2.4314	
number	2	2.000	4	11	
minimum	130	2.9	44	1.7	
maximum	420	11.5	908	11.9	

Lower Wenatchee Basin

	alkalinity	chloride	conductivity	nitrate	ortho phosphate
50th percentile	120	1.6	46.5	2.483069977	0.0115
90th percentile	291	7.585	300.19	8.03	0.2897
95% UTI	393.78	10.26	402.87	10.42	0.479
mean	149.0968	3.0234	104.3023	3.4822	0.0625
standard deviation	110.7945	3.5623	153.0762	3.5498	0.1773
number	31	53	86	85	22
minimum	16	0.2	21	0.005	0.0046
maximum	420	16.1	908	12.2	0.841

UTI – Upper Threshold Interval